bart
impact
program

TRENDS IN TRAFFIC PATTERNS AT THE BAY BRIDGE AND CALDECOTT TUNNEL

Traffic SF bay area
Bridges " "
Tunnels Caldecott tunnel
St. rail. SF bay area

working paper

The BART Impact Program is a comprehensive, policy-oriented study and evaluation of the impacts of the San Francisco Bay Area's new rapid transit system (BART).

The program is being conducted by the Metropolitan Transportation Commission, a nine-county regional agency established by state law in 1970.

The program is financed by the U.S. Department of Transportation, the U.S. Department of Housing and Urban Development, and the California Department of Transportation. Management of the Federally funded portion of the program is vested in the U.S. Department of Transportation.

The BART Impact Program covers the entire range of potential rapid transit impacts, including impacts on traffic flow, travel behavior, land use and urban development, the environment, the regional economy, social institutions and life styles, and public policy. The incidence of these impacts on population groups, local areas, and economic sectors will be measured and analyzed. The benefits of BART, and their distribution, will be weighed against the negative impacts and costs of the system in an objective evaluation of the contribution that the rapid transit investment makes toward meeting the needs and objectives of this metropolitan area and all of its people.

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BART IMPACT PROGRAM
TRENDS IN TRAFFIC PATTERNS
AT THE BAY BRIDGE AND CALDECOTT TUNNEL

July, 1977

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U.S. DEPARTMENT OF TRANSPORTATION

and

U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

BART IMPACT PROGRAM

TRENDS IN TRAFFIC PATTERNS AT THE BAY BRIDGE AND CALDECOTT TUNNEL

DOCUMENT No. DOT-BIP-WP 32-3-77
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16. Abstract

Utilizing multiple regression techniques, this paper presents an analysis of the effects of the opening of the Bay Area Rapid Transit (BART) System's transbay crossing on the traffic at two major highway facilities, the San Francisco-Oakland Bay Bridge and the Caldecott Tunnel. Looking at data collected semi-annually since 1965, it was found that there was a sudden shift in trend lines in 1974 after the BART transbay tube was opened. Vehicle volumes dropped, transit patronage jumped, but total person trips in the short run followed roughly the trends of the previous eight years. Transbay vehicle and transit traffic has increased at a more rapid rate since 1974, with mid-day off-peak transit patronage showing a large increase. While an important temporary phenomenon, the 1973-74 increase in gasoline prices was not found to contribute much to this sudden change in the long-term trends. BART also caused the removal of a substantial number of buses from the two facilities, effectively increasing their vehicle-handling capacity. This has resulted in higher traffic flow rates during the height of the peak periods.

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SAN FRANCISCO BAY REGION
CENTRAL AREA

Metropolitan Transportation Commission

BART: The Bay Area Rapid Transit System

Length: The 71-mile system includes 20 miles of subway, 24 miles on elevated structures and 27 miles at ground level. The subway sections are in San Francisco, Berkeley, downtown Oakland, the Berkeley Hills Tunnel and the Transbay Tube.

Stations: The 34 stations include 13 elevated, 14 subway and 7 at ground level. They are spaced at an average distance of 2.1 miles: stations in the downtowns are less than ½-mile apart while those in suburban areas are 2 to 4 miles apart. Parking lots at 23 stations have a total of 19,000 spaces. There is a fee (25 cents) at only one of the parking lots. BART and local agencies provide bus service to all stations.

Trains: Trains are from 4 to 10 cars long. Each car is 70 feet long and has 72 seats. Top speed is 80 mph with an average speed of 38 mph including station stops. All trains stop at all stations on the route.

Automation: Trains are automatically controlled by the central computer at BART headquarters. A train operator on-board each train can over-ride automatic controls in an emergency.

Magnetically encoded tickets with values up to $20 are issued by vending machines. Automated fare gates at each station compute the appropriate fare and deduct it from the ticket value. At least one agent is present at each station to assist patrons.

Fares: Fares range from 25 cents to $1.45, depending upon trip length. Discount fares are available for the physically handicapped, children 12 and under and persons 65 and over.

Service: BART serves the counties of Alameda, Contra Costa and San Francisco, which have a combined population of 2.4 million. The system was opened in five stages, from September, 1972, to September, 1974. The last section to open was the Transbay Tube linking Oakland and the East Bay with San Francisco and the West Bay.

Routes are identified by the terminal stations: Daly City in the West Bay, Richmond, Concord and Fremont in the East Bay. Trains operate every 12 minutes during the daytime on three routes: Concord — Daly City, Fremont — Daly City, Richmond — Fremont. This results in 6-minute train frequencies in San Francisco, downtown Oakland and the Fremont line where routes converge. In the evening, trains are dispatched every 20 minutes on only the Richmond — Fremont and Concord — Daly City routes. Service is provided weekdays only, between 6 A.M. and midnight. Future service will include a Richmond — Daly City route and weekend service. Trains will operate every 6 minutes on all routes during the peak periods of travel.

Patronage: Approximately 130,000 one-way trips are made each day. 200,000 trips are anticipated under full service conditions.

Cost: BART construction and equipment cost $1.6 billion, financed primarily from local funds: $942 million from bonds being repaid by the property and sales taxes in the three counties, $176 million from toll revenues of transbay bridges, $315 million from federal grants, and $186 million from interest earnings and other sources.

January 1977

SUMMARY

This study analyzes data collected semiannually since 1965 of traffic crossing San Francisco Bay and since 1967 of traffic passing through the Berkeley Hills via Caldecott Tunnel, to determine the effect of the opening of the Bay Area Rapid Transit System (BART) transbay line. Motor vehicle volumes for typical weekdays and for the morning and afternoon peak periods were analyzed at both locations; for transbay traffic midday vehicle volumes and daily, peak period, and midday transit patronage trends were also studied.

There was a sudden shift in trend lines in 1974; vehicle volumes dropped, transit patronage jumped, but total person trips in the short run followed roughly the trends of the previous eight years. At Caldecott Tunnel, the trend in person trips appears to have remained about the same after 1974, but transbay vehicle and transit traffic has increased at a more rapid rate since then. The increase in transit patronage is particularly noticeable between the morning and afternoon peaks and probably represents new trips by shoppers and sightseers. While other factors, such as the increase in the price of gasoline between October 1973 and July 1974 may have contributed a little to the sudden change in the long-range trends in 1974, it is believed that the major cause was the opening of the BART network to transbay travel.

As a result of the removal of a substantial number of buses from the Bay Bridge and Caldecott Tunnel, the capacity of the former appears to have increased slightly, and that of the latter significantly. This is evidenced by higher traffic flow rates during the height of the peaks. Highly significant flow reductions were found from 0600 to 0642 at the Bay Bridge, and for a shorter period early in the morning at Caldecott Tunnel.

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1. Introduction

In 1962 the three central counties of the San Francisco Bay Area committed themselves to the construction of the Bay Area Rapid Transit (BART) system. The region thereby became the first one in the United States to build an entirely new urban rail network (as distinguished from single lines in Cleveland and Camden-Lindenwold, N.J.) since World War II. BART was the first such project to be superimposed on a preceding, extensive urban freeway system, and the first to be designed primarily for regional travel, as distinguished from intra-city trips. As a result, BART has become the focus of much interest in the United States and beyond, and its performance and "success" will be watched carefully for many years to come.

A major objective for the construction of BART was stated to be the relief of traffic congestion on parallel freeways, highways and bridges. "The losses from delays through traffic congestion already are appreciable. Unless averted, they will become much greater in the future . . . The rapid transit system . . . would eliminate most of the estimated peak-hour highway deficiencies at four major bottlenecks . . ." Two of these bottlenecks were listed as the Transbay and the Berkeley Hills "gateways."[1]

The Institute of Transportation Studies (ITS) has conducted semiannual traffic counts at the Bay Bridge and the Caldecott Tunnel since 1959 (Figure 1). Originally undertaken to measure the effect on traffic of major capacity increases (rebuilding the Bay Bridge, adding a third 2-lane tube to Caldecott), the counts have been maintained to be used as a general trend data source, and are eminently suitable for analyzing the effect of the introduction of BART service at these screen lines.

In September 1974 the last section of the BART network opened to the public. In 1977 the level of service is still considerably below that envisioned by the designers and demand estimators in 1962; peak period headways are six minutes instead of two, there is no direct service between the Richmond Line and the West Bay, and there is no weekend service. However, since data covering the first two and one-half years of full-network operation are available, it was felt useful to investigate whether any impacts on highway and bridge traffic had become clearly established.

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[1]Stanbery, Van Beuren. "The Economic Effects and Benefits of Bay Area Rapid Transit." In: Composite Report Bay Area Rapid Transit. San Francisco, May 1962.

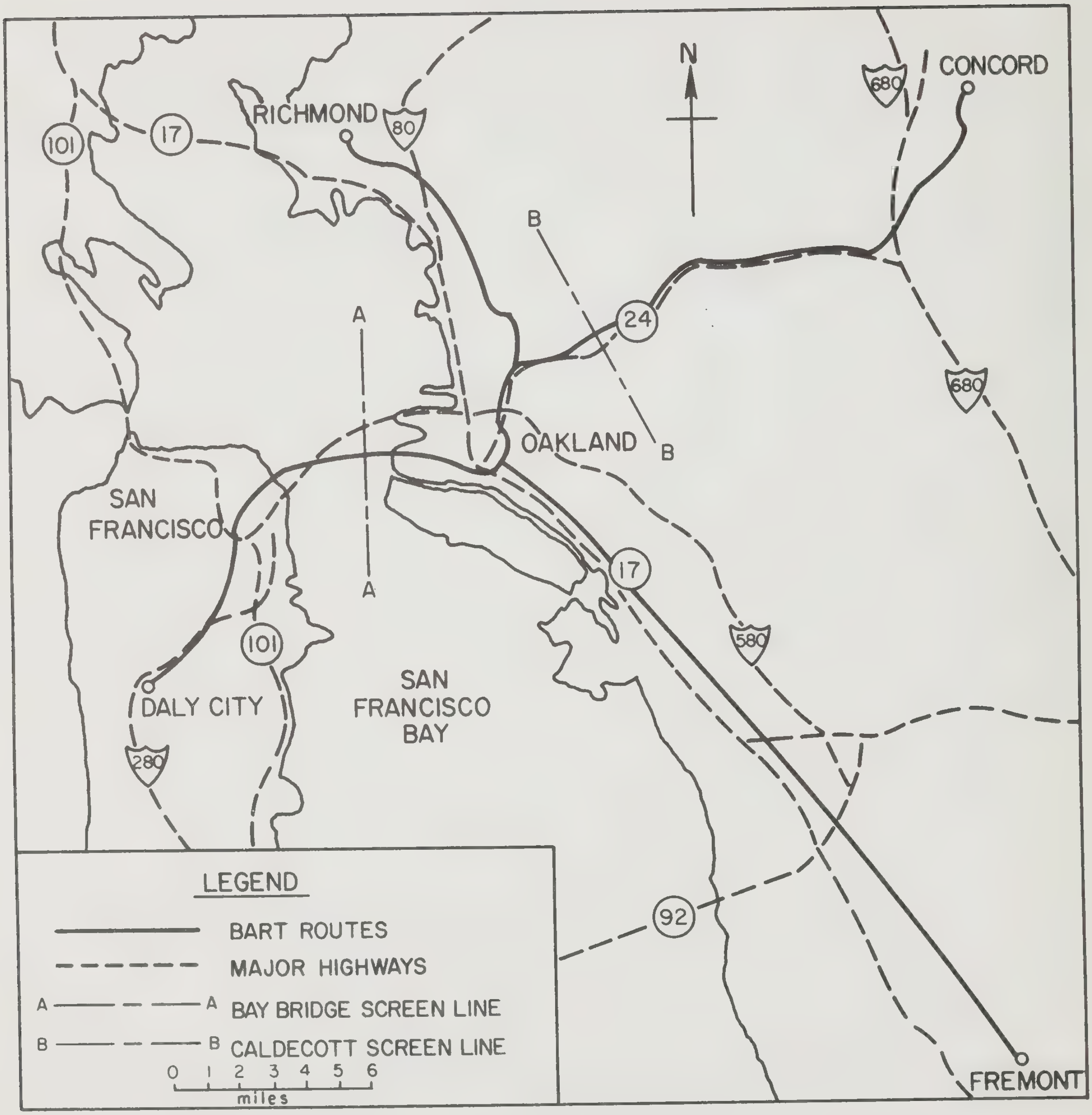

FIGURE 1

LOCATION OF BAY BRIDGE AND CALDECOTT SCREEN LINES.

This paper reports on such an investigation. A brief chronology of events which may have affected traffic in the areas of the Bay Bridge and the Caldecott Tunnel during the period under study is given. Data sources are described, followed by a multiple regression analysis of these data to see whether the introduction of BART had a significant effect on trends. A separate analysis of peak period, peak direction flows by 6-minute intervals is then described. A brief comment on the original estimate of the BART planners is also included. Finally, conclusions arising from this investigation are summarized.

2. Chronology of Events

During the period of 1965 to 1977 a number of events other than the construction and opening of BART occurred to influence traffic behavior. The effect of some of these lend themselves to quantitative analyses, that of others only to speculation. The following list is doubtlessly not complete. Not all of the major extraneous events shown could be included in the analysis.

2.1 During the entire period

2.11 Population

There was a steady increase in population in the 9-county Bay Area in the period. However, in the three counties which contribute most directly to traffic at the Bay Bridge and Caldecott Tunnel -- Alameda, Contra Costa, and San Francisco -- this increase ended in 1972, after which there was a slight drop in population to 1975 and a period of no change through 1976. See data in Appendix B.

2.12 Employment

Employment data are available only for the total of five counties -- the three mentioned above plus Marin and San Mateo. "Service employment" ("E6" through "E9" as defined in Appendix A) showed an overall steady rate of growth in the period from 1966 to 1976; however, there is a marked seasonal fluctuation. Employment in April (the month of the Spring traffic counts) is roughly 1% below the annual mean, that in October (Fall counts) 1% above that mean. "Basic employment" suffered a marked

decline from 1970 through 1972, probably caused by the ending of jobs connected with the Vietnam War effort and the movement of some labor-intensive industries out of the region and even out of the country. After a slight increase in basic employment in 1973 and 1974, a new downward trend occurred in 1975 and 1976. Again, October figures in each year tend to be higher than April numbers. See data in Appendix B.

2.13 Inflation

Since many transportation prices remained constant in current dollars during all or most of the period (i.e.: gasoline tax, bridge tolls) and some rose only slightly (i.e.: transbay bus fares), some aspects of transportation costs may be said to have dropped in terms of constant dollars during the period. However, note item 2.14.

2.14 Gasoline prices and availability

Gasoline prices held fairly steady (in current dollars) from 1965 to 1973 and again from 1975 to 1977. The sudden jump in prices between late 1973 and July 1974, and the temporary shortage of supplies in early 1974 are listed in 2.22.

2.1 Specific events

2.21 Transit Strikes

Strikes have, of course, an immediate effect on traffic flow. However, strikes of more than a few days duration also leave a residual effect; some ex-transit passengers will have found an alternative method of transportation which proves itself more desirable to them to the extent that the modal switch becomes permanent. During the period of this study, transit strikes occurred as follows:

1966 - May and June -- Greyhound Lines
1970 - June (19 days) -- A. C. Transit
1973 - July and August (36 days) -- BART
1974 - July and August (62 days) -- A. C. Transit
1976 - March - May (39 days) -- S. F. Muni

The strike on the S. F. Muni affected travel across the Bay in that transit passengers with origins or destinations beyond walking distance from a BART station or the transbay Bus Terminal were deprived of their usual mode of transportation within San Francisco, and in the aggregate, made fewer trips across the Bay during that period. (Data collected in April 1976 and used in this analysis were adjusted to eliminate the effect of this strike).

2.22 Gasoline shortage and price rise

The "fuel crisis" was at its peak in February and March 1974, when vehicle traffic across the Bay Bridge, for example, dropped 10% as contrasted to a trend line growth rate of about 3% prior to that time. Prices began to rise in late 1973 and reached a new plateau in mid-1974.

2.23 Transportation network changes

1969 (September) - Start of one-way toll collection at the Bay Bridge.

1970 - Grove Shafter Freeway (Route 24) opened below the west portal of the Caldecott Tunnel to the MacArthur Freeway (I-580). Route 24 Freeway expansion completed from below east portal of the Caldecott Tunnel to west of Lafayette.

1971 - Route 24 Freeway expansion completed from west of Lafayette to Walnut Creek (interchange with I-680).

1973 (May) - BART Concord route opened, with shuttle service at 10-minute headways between Concord and MacArthur (connecting to trains operating between Richmond and Fremont).

1974 (April) - Inauguration of traffic metering at the westbound approach to the Bay Bridge. Effect on capacity probably confined to that caused by ability of buses and trucks to start up the 3% ramp grade at full speed instead of at a crawl rate.

1974 (September) - BART transbay tube opened, completing BART route network. Service operated at 6-minute headways transbay and 12-minute headways through the Berkeley Hills.

1970-1975 (in stages) - Introduction of permit lanes for buses and car pools at the Toll Plaza of the Bay Bridge as follows:

April 1, 1970:	Permit lane for A.C. Transit buses.
December 8, 1971:	Permit lane for car pools.
May 1, 1972:	Reduced monthly toll rate for car pools.
March 1, 1975:	Free lanes for buses and car pools.

The effect of these events on vehicle capacity (as distinguished from demand) is probably zero.

3. Data Sources

3.1 ITS traffic data collection program

The Institute of Transportation Studies (formerly the Institute of Transportation and Traffic Engineering - ITTE) has been conducting traffic counts at regular intervals at the Bay Bridge and Caldecott Tunnel since 1959. In this study the data collected since 1965 at the Bay Bridge and since 1967 at Caldecott Tunnel have been used. The general format and content of each counting set is as follows:

3.11 Total vehicle counts by direction, by 6-minute intervals in the 3-hour peak periods (0600-0900 and 1600-1900*) and by 30- or 60-minute intervals at other times. (Since October 1976, peak period intervals at the Bay Bridge have been changed to 5 minutes because of new equipment installed at that location). Generally two full days of machine data were obtained, sometimes three.

3.12 Classification of vehicles by type. This manual survey is performed for 12 hours from 0630 for one day. At the

*The 24-hour clock is used in this report.

Bay Bridge, all vehicles are classified during the peak periods and 50% at other times; at Caldecott Tunnel the sample size is about 40% at all hours.

3.13 Occupancy of passenger cars. This manual survey is also conducted on one day for twelve hours from 0630. Sample size is designed to be about 30%, although in some counts this was not achieved. At the Bay Bridge toll plaza, car pool lanes are sampled separately.

3.14 Mass transit passenger counts. These are conducted for one day, with as close to a 100% sample as possible being obtained. At Caldecott Tunnel no transit counts were taken until the opening of BART service, since most of the bus passengers in the pre-BART period were traveling to/from San Francisco and were counted at the Bay Bridge.

3.2 Traffic data used

Specifically, the Bay Bridge data starting from Spring 1965 (Report A-24), are complete through Spring 1977 (Report A-48) with the exception of the following:

Fall 1969 - No data except machine counts of total traffic
Spring 1972 - No Westbound Greyhound data
Fall 1973 - No Eastbound machine counts of total traffic

No estimates were made for the missing Fall 1969 data since no basis for estimation could be determined. However, since an adequate basis for estimating the missing Spring 1972 and Fall 1973 data was determined, estimates were made for these cases.

The Caldecott Tunnel data began in Spring 1967 (Report C-11), and continued through Spring 1977 (Report C-34). Unfortunately, data from 1965 and 1966 are unavailable because of mechanical failures and unconducted surveys. Also missing are traffic data on Fish Ranch Road* for Spring 1970 and Spring 1971. Sufficient basis for estimating the Fish Ranch Road data were determined to exist.

For regression analysis described in Section 4 of this report, all data sets were utilized. For the special analysis of the shape of the peak traffic

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*Fish Ranch Road is a two-lane, winding alternative route to Caldecott Tunnel for traffic to and from Berkeley; it crosses the Berkeley Hills at an elevation 400 ft. above the highest point of Caldecott Tunnel.

flow curves, discussed in section 5, the following data sets were utilized:

Bay Bridge: "Before BART" - Spring 1972 through Fall 1973.

"After BART" - Spring 1975 through Fall 1976.

Both sets from 1974 were omitted; the Spring count occurred just as the fuel shortage was ending and appeared to be somewhat atypical; the Fall count took place just one month after BART transbay service commenced and before new permanent patterns may have been established.

Caldecott: "Before BART" - Fall 1971 through Spring 1973.

"After BART" - Spring 1975 through Fall 1976.

The omission of the Fall 1973 count was made to delete the data collected while BART was operating the shuttle service terminating at MacArthur station; the reasons for omitting the 1974 sets are the same as mentioned for for the Bay Bridge data.

In both locations, four sets of "before" data were used, both to balance the four sets of "after" data available and to give a sample size in the "before" data set which would yield statistically valid results. Because at least two days were counted in each set, each group consists of at least eight days.

3.3 Demographic data

The data sources for the different demographic variables are given here; Appendix B tabulates the figures used. Data for 1977 were not available; in preference to introducing possible errors by haphazard extrapolation, the Spring 1977 traffic counts were only used in the simple regression analysis against time (sections 4.13 and 4.23 below) and were omitted from regression involving demographic variables.

3.31 Population

The 3-county total population data are taken from two sources. For 1965 through 1975 the data are from the California Statistical Abstract[2], which reports estimated population for each county as of July 1 of each

[2] California Statistical Abstract, Documents Department, State of California. "Estimated Population of California Counties," Population Research Unit, Department of Finance.

year. Series E-1 population estimates of the California Department of Finance were used for county population estimated for January 1, 1976 and 1977. These numbers were interpolated to produce April and October estimates to correspond to the ITS Fall and Spring traffic counts.

3.32 Employment

The Bay Region (5-county SMSA) Employment data are taken from a California Employment Development Department document entitled, Wage and Salary Workers in Non-agricultural Establishments, by Industry, San Francisco-Oakland Metropolitan Area.[3] The monthly statistics for April and October were used. These data are available only from 1966 through 1976. No estimates of the missing 1965 data has been made.

3.33 Price Index

The Consumer Price Index for the San Francisco-Oakland Metropolitan Area is taken from the U. S. Statistical Abstract.[4] One value per year is given from 1965 through 1976. This Index is so constructed that 1967 has a value of 100.0. Subsequent monetary variables are converted to constant 1967 dollars using the price index for each year.

3.34 Gasoline Prices

The gasoline price in the San Francisco-Oakland Metropolitan Area is taken from industry statistics compiled weekly in the "Oil and Gas Journal."[5] The gas price quoted is the

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[3] Wage and Salary Workers in Non-agricultural Establishments, by Industry, San Francisco-Oakland Metropolitan Area, 1966-1976, Health and Welfare Agency, California Employment Development Department, Employment Data and Research Division.

[4] Statistical Abstract of the United States, Bureau of the Census, U. S. Department of Commerce. "Consumer Price Indexes," U. S. Bureau of Labor Statistics, "Monthly Labor Review."

[5] "Oil and Gas Journal," Petroleum Publishing Company, Tulsa, Oklahoma.

pump price, including tax, in cents per gallon for "a major brand regular" in the city of San Francisco on a typical day of the week. The data values used are the typical daily pump prices corresponding most closely to the middle of April and the middle of October each year. The gas prices have been converted to constant 1967 dollars for input into the analysis. The data are complete from April 1965 through December 1976.

3.35 Taxable Sales

Taxable Sales for the 3-county area are taken from the State Board of Equalization Quarterly, "Taxable Sales in California (Sales and Use Tax)."[6] The data are reported for self-assessed transactions taxable under the sales and use tax laws in current dollars for each California county. The annual value of the 3-county sum has been used rather than the quarterly values in order to avoid comparing October traffic with a taxable sales figure in which the Christmas shopping peak distorts the representation of October retail activities. The data have been converted to constant 1967 dollars for use in the regression analysis.

3.36 Motor Vehicle Registration

Motor vehicle registration in the 3-county area has been compiled from the California Department of Motor Vehicles' monthly publication, "Statement of Transactions and Fees Collected."[7] The total of all vehicles (exempt and fee paid) registered at the end of each year has been used. Semiannual statistics would have been unreliable prior to 1976 because, under the old vehicle registration program, which involved reregistering all vehicles in January-February, monthly totals did not always represent the number of active vehicles.

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[6] Taxable Sales in California (Sales and Use Tax), California State Board of Equalization.

[7] Statement of Transactions and Fees Collected, Department of Motor Vehicles, State of California.

4. Regression Analysis of Historic Traffic Trends

The previously described data were analyzed by standard multiple regression techniques. The variable names are defined in Appendix A.

Six sets of multiple regression equations were developed and inspected. Three of the sets were for all the data from 1965 through 1977; the other three involved dividing the data into "before BART" and "after BART" periods. Two of the sets involved all variables (except where otherwise noted), two excluded the variable YEAR, and two excluded all independent variables except YEAR. Table 1 serves as a guide through the discussion which follows.

TABLE 1 - GUIDE TO MULTIPLE REGRESSION DISCUSSION

Independent Variables	Entire Study Period (1965-1977)	"Before" and "After" Data Separated
All used, except as otherwise stated in the discussion	Discussed in 4.11 Listed in Table 2	Discussed in 4.21 Not tabulated
Variable YEAR excluded	Discussed in 4.12 Listed in Table 3	Discussed in 4.22 Listed in Table 5
Variable YEAR only	Discussed in 4.13 Listed in Table 4 Plotted in Fig. 2	Discussed in 4.23 Listed in Table 6 Plotted in Figs. 3-13

It is in the nature of the multiple regression process that the equation which "fits best," i.e., produces the highest multiple correlation coefficient and meets all significance tests, may still fail to pass the common sense test in that the coefficient of one or more of the independent variables may have the wrong sign. This occured in several cases in this analysis, especially when the basic employment or total employment were introduced in the stepwise procedure. The declines in basic employment mentioned in 2.12 took place during periods when traffic volumes were growing, but that does not mean that declines in employment cause traffic increases. Therefore, equations involving such "wrong" signs were discarded.

4.1 Regression equations for the entire study period

When the entire period from 1965 to 1977 is combined in a regression analysis, a well-fitting equation (R^2 close to 1.0) would indicate that the events

of 1974 had little or no effect on trends. This was investigated first.

4.11 <u>Regression will all independent variables</u>

The results of analyzing the complete 12½-year study period, using all available independent variables, produced the equations for each of the thirteen dependent variables summarized in Table 2. It can be noted at a glance that eleven of the thirteen equations resulted in a multiple regression coefficient (R^2) of more than 0.75. One of these equations, however, is a curiosity: the traffic using Fish Ranch Road as a proportion of all traffic through the Berkeley Hills gateway decreased consistently with increases in motor vehicle registration, employment, and -- as a look ahead at Table 4 shows -- with time. This phenomenon has nothing to do with BART. The first major impetus to reduction in the use of the inferior Fish Ranch Road alternative to the Caldecott Tunnel was the opening of the Grove-Shafter Freeway in 1970; more recently, street barriers installed by the City of Berkeley in the vicinity of Claremont Avenue have also contributed to making this route less attractive. Further consideration of this variable FRRVV in the context of BART impact is therefore fruitless.

The other dependent variable which will be dropped from further discussion is BBOCCP, the weighted passenger car occupancy factor for the period from 0630 to 1830. As the data for the regression equation in Table 2 show, this factor does not correlate with any of the independent variables. It has remained relatively constant during the entire study period. (For the same reason, the passenger car occupancy data for Caldecott Tunnel were not processed.) However, occupancy will be watched over the next few years to look for possible increases caused by car pool priority programs.

Ten of the eleven remaining equations correlate at levels which can be referred to as ranging from fairly high to high. This suggests that the opening of BART and the fuel

TABLE 2 -- MULTIPLE REGRESSION EQUATION DATA -- ENTIRE STUDY PERIOD -- ALL INDEPENDENT VARIABLES

Dependent Variable	Constant	Independent Variable 1		Independent Variable 2		R^2	F Significance Level+
		Coefficient	Name	Coefficient	Name		
BBVV24	-195,420	2,410.7	YEAR	149.84	POPL	.91256	0.000
BBVVAM	- 58,533	34.662	POPL			.75235	- 0 -
BBVVPM	- 12,305	161.88	YEAR	14.215	POPL	.76566	0.000
BBVVMD	-152,390	892.65	YEAR	90.383	POPL	.86498	0.000
BBMT24	- 90,901	255.74	E678			.81602	- 0 -
BBMTAM	- 20,128	68.615	E678			.95351	- 0 -
BBMTPM	- 22,518	72.618	E678			.92058	- 0 -
BBMTMD	- 37,371	82.359	E678			.65394	0.000
BBOCCP	1.9408	- 0.00109	EBASIC	-0.000050	MVREG	.17009	0.187
CTVV24	-426,520	3,017.5	YEAR	217.67	POPL	.94059	0.000
CTVVAM	- 59,895	525.25	YEAR	32.564	POPL	.90384	0.000
CTVVPM	- 90,251	491.47	YEAR	45.321	POPL	.92948	0.000
FRRVV	14.346	- 0.00485	MVREG	-0.24607	YEAR	.93887	0.000

+ : - 0 - means that the F significance level << 0.001.

crisis events did not cause a major disruption in the trends analyzed. However, it must be recognized that the regression analysis combines nineteen "before BART" counts at the Bay Bridge and fifteen at the Caldecott Tunnel with only five† "after BART" counts at each location, and that the pre-BART trends might therefore predominate when the regression line is fitted. This will be discussed further in Section 4.2.

In general, the vehicle volume trends correlate with time, as represented by the date of the survey (variable YEAR) and with the 3-county population. All coefficients are positive, which is to be expected. The mass transit passenger data for transbay trips correlate with the number of employees in trade, finance and service jobs (variable (E678) in the five-county standard metropolitan statistical area (SMSA).* In the case of peak period travel, this correlation is quite high. The midday transit trip trend (variable BBMTMD) shows the poorest correlation; this statistic was strongly influenced by the opening of transbay BART service, which factor is not allowed for at this stage of the analysis.

4.12 Regression excluding the time factor

In order to identify the demographic factors which influence those traffic trends correlating most closely with time, the factor YEAR was excluded from the next set of correlation computations. In Table 3, which presents the results, those equations which were not correlated with YEAR in Table 2 are, of course, unchanged. The primary factor replacing YEAR in the other equations is either the 3-county population, or the 5-county labor force in the trade, finance and service industries. As a secondary factor, the 3-county taxable retail

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†The sixth (Spring 1977) post-BART count is not included because demographic data for this date are not yet completely available.

*Employment data for the 3 BART counties alone are not available.

TABLE 3 -- MULTIPLE REGRESSION EQUATION DATA -- ENTIRE STUDY PERIOD -- INDEPENDENT VARIABLE "YEAR" EXCLUDED

Dependent Variable	Constant	Independent Variable 1		Independent Variable 2		R^2	F Significance Level+
		Coefficient	Name	Coefficient	Name		
BBVV24*	-342,070	110.22	E678	191.27	POPL	.90633	0.000
BBVVAM	- 58,533	34.662	POPL			.75235	- 0 -
BBVVPM*	- 20,539	7.8871	E678	16.180	POPL	.77125	0.000
BBVVMD*	-302,360	144.55	POPL	5.7022	TXSALES	.85355	0.000
BBMT24	- 90,901	255.74	E678			.81602	- 0 -
BBMTAM	- 20,128	68.615	E678			.95351	- 0 -
BBMTPM	- 22,518	72.618	E678			.92058	- 0 -
BBMTMD	- 37,371	82.359	E678			.65394	0.000
CTVV24*	-712,500	126.46	E678	313.60	POPL	.91422	0.000
CTVVAM*	-158,800	68.499	POPL	3.3706	TXSALES	.88687	0.000
CTVVPM*	-137,720	61.381	POPL	20.412	E678	.90531	0.000

+ : - 0 - means that the F significance level << 0.001

* : Equation affected by excluding the variable YEAR. Other equations are the same as in Table 2.

sales appear in two equations. All the correlation coefficients (R^2) of the six new equations are only slightly lower than the corresponding coefficients of the equations they replace. This is to be expected since both population and work force in the trade/finance/services group are themselves closely correlated with the calendar year.

4.13 Simple regression against time

The third correlation computations used only the independent variable YEAR to produce a set of equations which can be plotted for visual inspection.* The variable YEAR was chosen both because the resulting graphs are then true trend lines and because YEAR is more often the best correlated variable than any of the other independent variables. The results are shown in Table 4. The first equation is plotted in Figure 2 to illustrate the hidden inaccuracies in using the data from the entire study period. The regression processes always find a best fit line. But when Figure 2 is contrasted with Figure 3, (p.24) where pre-BART and post-BART data are separated, it can readily be seen that the line in Figure 2 fails to represent the pattern of the individual data points. Therefore, the analysis described in the next section was undertaken, and the plots of the remaining equations in Table 4 have been omitted.

4.2 Regression equations for separated pre-BART and post-BART data

In order to focus more precisely on the impact of the "events of 1974" (the opening of the transbay BART line and the energy crisis), the traffic and demographic data were separated into pre-BART data comprising the following periods:

Pre-BART: At the Bay Bridge from Spring 1965 to Fall 1973
At Caldecott from Spring 1967 to Spring 1973.

Post-BART: At both locations from Fall 1974 to Fall 1976 where demographic variables were involved, and to Spring 1977 for regression against time only.

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*The Spring 1977 counts are included in this analysis, since no demographic variables are involved.

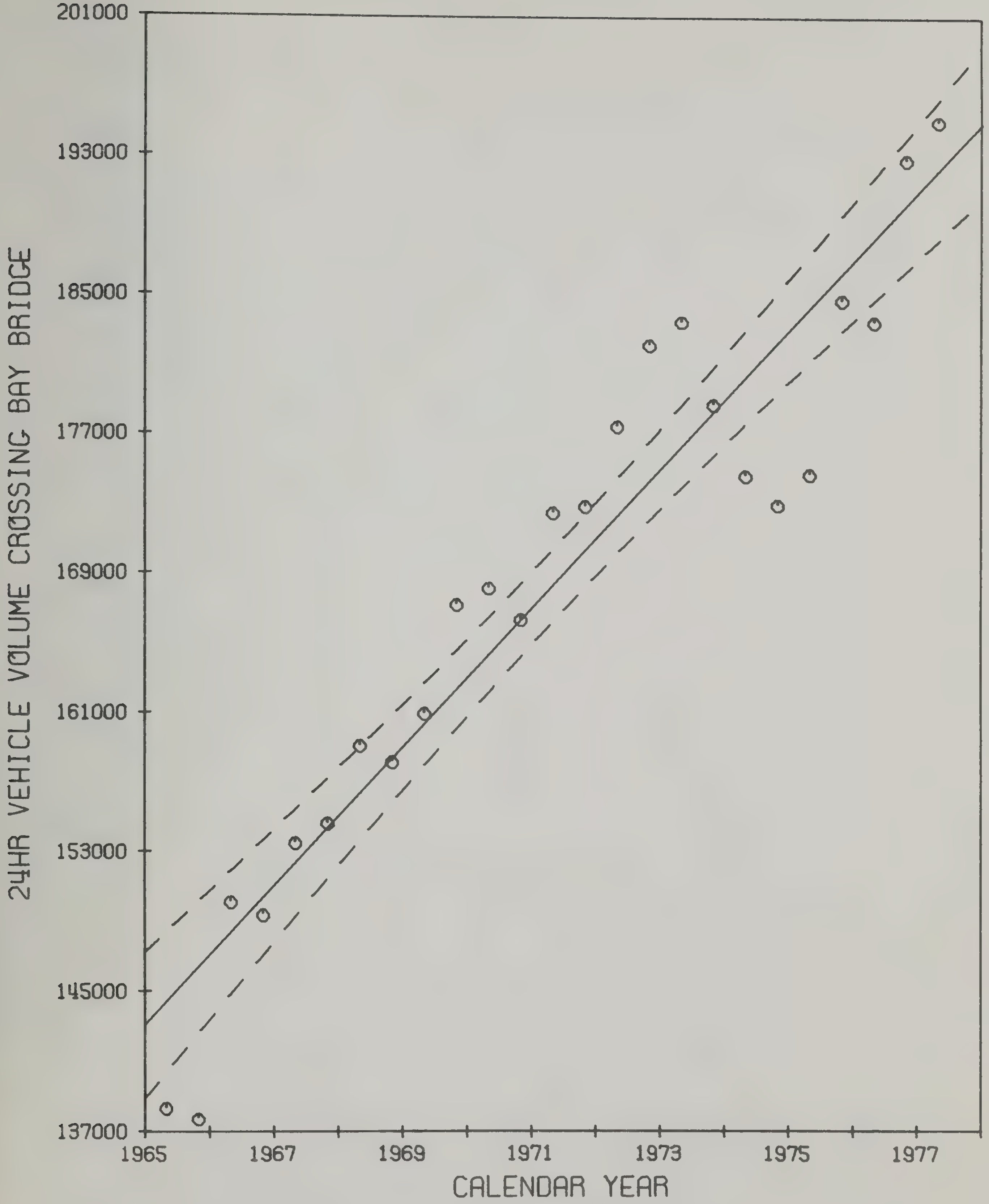

FIGURE 2

TREND IN 24-HOUR VEHICLE TRAFFIC ACROSS THE BAY BRIDGE — REGRESSION LINE FOR ALL DATA FROM 1965 THROUGH 1977.

TABLE 4 -- SIMPLE REGRESSION EQUATION DATA -- ENTIRE STUDY PERIOD -- INDEPENDENT VARIABLE "YEAR" ONLY

Dependent Variable	Constant	Coefficient of Variable "YEAR"	R^2	F Significance Level+
BBVV24	143,102	3,986.5	.89966	- 0 -
BBVVAM	20,000	326.96	.61132	0.000
BBVVPM	19,752	321.89	.69306	- 0 -
BBVVMD	52,346	1,756.0	.86149	- 0 -
BBMT24	32,829	4,615.4	.81424	0.000
BBMTAM	12,700	1,282.6	.94243	0.000
BBMTPM	12,439	1,322.8	.91509	0.000
BBMTMD	2,982.2	1,430.5	.65248	0.000
CTVV24	76,397	4,163.4	.90894	- 0 -
CTVVAM	15,309	706.24	.88819	- 0 -
CTVVPM	14,445	735.14	.88724	- 0 -

+ : - 0 - means that the F significance level << 0.001

The Spring 1974 data sets were omitted at both locations because of the effects of the fuel shortage on traffic at that time. At Caldecott, the Fall 1973 data were also deleted because they were taken while BART operated the Concord-MacArthur shuttle service, a noncomparable, temporary condition.

It must be emphasized that there are only five or six data sets in the post-BART period. This does not produce very reliable equations, as the resulting values of the F significance levels for the "After" conditions in Tables 5 and 6 indicate. Hopefully, these post-BART trends can be extended and made statistically sounder for the Caldecott location. However, the Bay Bridge toll increase in 1977 will introduce a new independent variable at the transbay screenline, and may well cause a new interruption in the trend lines at that location.

4.21 Regression with all independent variables

In all the equations computed for this analysis, only the first independent variable was statistically acceptable; thus the results in this case turned out to be simple, rather than multiple regression. The variable YEAR was the most closely correlated in all but one of the pre-BART equations and in seven of the nine post-BART equations which showed an F significance level of less than 0.1. Since these results are therefore almost the same as those to be discussed in section 4.23 below, they are not further dealt with here, nor are they shown in a separate table.

4.22 Regression excluding the time factor

The variable YEAR was again excluded in order to identify those demographic variables which related most closely with the traffic trend variables. Table 5 shows the results. The pre-BART equations generally involved the same two variables, population and trade/finance/service employment, as do the equations which describe the entire 12-1/2-year trends. The correlation coefficient R^2 for seven of the eleven pre-BART equations is higher than the corresponding coefficient for the "entire period" equations, which suggests that the trend disruption in 1974 contributed, in some instances considerably, to the unexplained variations found in the

TABLE 5 -- MULTIPLE REGRESSION EQUATION DATA -- "BEFORE" AND "AFTER" DATA POINTS SEPARATED -- INDEPENDENT VARIABLE "YEAR" EXCLUDED

Dependent Variable	Before or After	Constant	Independent Variable 1		Independent Variable 2		R^2	F Signif. Level+	R^2 for 12½-year Data Regression (from Table 3)
			Coefficient	Name	Coefficient	Name			
BBVV24	Before	23,706	249.52	E678*			.88406	- 0 -	.90633
	After	- 98,317	410.75	E678*			.95439	0.004	
BBVVAM	Before	5,727.8	28.925	E678*			.85310	0.000	.75235
	After	F significance level of best equation is above the 10% level.							
BBVVPM	Before	10,069	20.292	E678*			.78456	0.000	.77125
	After	- 28,016	37.723	ETOTL			.94139	0.006	
BBVVMD	Before	3,409.8	64.804	E678*	14.068	MVREG	.89985	0.000	.85355
	After	- 57,781	185.69	E678*			.93259	0.008	
BBMT24	Before	- 8,819.3	107.51	E678*			.91928	- 0 -	.81602
	After	6,213.0	125.78	E678*			.81399	0.036	
BBMTAM	Before	10,276	50.793	E678*			.97147	- 0 -	.95351
	After	-568,530	253.70	POPL*			.90780	0.012	
BBMTPM	Before	- 9,386.5	48.858	E678			.93507	- 0 -	.92058
	After	F significance level of best equation is above the 10% level.							
BBMTMD	Before	1,928.6	11.444	E678*			.52979	0.002	.65394
	After	F significance level of best equation is above the 10% level.							
CTVV24	Before	-955,080	404.54	POPL*	20.508	TXSALES	.92592	0.000	.91422
	After	-2,370,900	1,056.3	POPL*			.92846	0.008	
CTVVAM	Before	-151,320	65.179	POPL	3.4119	TXSALES	.76281	0.000	.88687
	After	-372,570	167.58	POPL			.79953	0.041	
CTVVPM	Before	-182,600	85.652	POPL*			.83511	0.000	.90531
	After	-399,570	178.79	POPL*			.90562	0.013	

+ : - 0 - means that the F significance level << 0.001.

* : If variable YEAR had not been supressed, it would have been selected by the stepwise regression procedure instead of the variable indicated.

equations in Table 3. One of the three equations with substantially lower values for R^2 than found in Table 3 is that describing midday transit patronage across the Bay; the fluctuations which cause the low correlation in this case can be explained by the fact that Spring counts generally include traffic to Golden Gate Fields race track while Fall counts do not. The other two equations with substantially reduced values of R^2 are for the two peak vehicle volume trends at Caldecott; in this case the opening of the Grove-Shafter/Route 24 freeway, chronicled in 2.23 above, probably explains the lack of a linear trend. If more data points had been available, separate trend lines for 1967-69 and 1970-73 might have been developed to test this hypothesis.

The post-BART equations suffer from the paucity of data points. The F significance level of several of them is above 10%, and these were therefore considered unacceptable. The independent variables found to correlate most closely are the 3-county population and the 5-county trade/finance/service or total employment.

4.23 <u>Simple regression against time</u>

Simple regression against time was again used to plot graphs for a visual impression of the contrast between pre-BART and post-BART trends. The results are tabulated in Table 6 and shown in Figures 3-13. All figures clearly show a discontinuity around 1974. As the discussion in Section 4.3 will show, the increased cost of gasoline was not found by the regression technique to be responsible for any part of this change in the trend lines, although some causal attribution cannot be ruled out. It would appear, based on the evidence of this analysis, that BART can be assigned the major responsibility for the trend shifts depicted.

The trends in vehicle volumes are shown in Figures 3-6 for the Bay Bridge and 11-13 for Caldecott. In all these the post-BART regression line starts out considerably below the level at which the pre-BART line left off. At the Bay Bridge,

the post-BART trend lines have steeper slopes than the pre-BART lines, suggesting that a "catching up" is in progress. At Caldecott, the slopes (i.e., rate of growth of traffic) became slightly less after 1974. (Numerical values for these slopes can be found in Table 6.)

Transit riding trends across the Bay show a different form of discontinuity in 1974 (Figures 7-10). There is an upward jump -- in the case of the 0900-1600 traffic it is a leap of more than 250% -- to new trend lines which, just as in the case of the vehicle volume lines, then continue at a steeper slope than previously. The 1974 discontinuity is discussed again in section 4.4.

At the transbay screen line, the total post-1974 travel is growing at a faster rate than previously, with transit carrying a greater share than before. Some of this increase can be attributed to midday traffic increases on transit, consisting partly of sightseers on BART. Peak period vehicle volumes have been growing at a faster rate since 1974 than before, but one can postulate that this rate of increase cannot be sustained because of capacity constraints, not to mention the effects of higher tolls.

At Caldecott there appears to have been an abrupt shift in modal split (the absence of pre-BART transit data does not permit quantifying this shift), but little effect, if any, on the overall rate of growth of traffic.

4.3 Fuel cost -- the missing variable

One will note that the independent variable representing the cost of gasoline appears nowhere in the preceding tabulations and discussions. This variable correlated very poorly with all the dependent traffic variables: the value of R^2 for direct regression with the vehicle volume variables ranged from -0.3689 to -0.0196, and with the transit riding variables from +0.0485 to +0.0108. In the stepwise procedure, gasoline cost was not even selected as a secondary or tertiary variable which could add to the explanatory quality of the multiple regression equations.

TABLE 6 -- SIMPLE REGRESSION EQUATION DATA -- "BEFORE" AND "AFTER" DATA SEPARATED -- INDEPENDENT VARIABLE "YEAR" ONLY

Figure Number	Dependent Variable	Before or After	Constant	Coefficient of Variable "YEAR"	R^2	F Significance Level+
3	BBVV24	Before	139,460	5,094.4	.95770	0.000
		After	80,501	9,334.2	.93431	0.002
4	BBVVAM	Before	19,036	605.82	.91322	0.000
		After	14,947	708.80	.59897	0.071
5	BBVVPM	Before	19,279	462.70	.75343	0.000
		After	14,837	730.00	.64404	0.055
6	BBVVMD	Before	50,199	2,396.9	.94669	0.000
		After	22,715	4,249.0	.94018	0.001
7	BBMT24	Before	41,952	2,019.7	.92809	- 0 -
		After	49,789	3,913.2	.94413	0.001
8	BBMTAM	Before	14,039	904.15	.97604	- 0 -
		After	9,129.0	1,711.1	.95281	0.001
9	BBMTPM	Before	14,041	863.23	.94675	- 0 -
		After	17,015	1,052.8	.82172	0.013
10	BBMTMD	Before	7,175.3	239.14	.64493	0.000
		After	13,598	869.89	.48467	0.124
11	CTVV24	Before	71,529	5,985.4	.93837	- 0 -
		After	66,496	5,008.4	.94277	0.001
12	CTVVAM	Before	14,603	971.51	.87194	0.000
		After	13,219	899.94	.86153	0.008
13	CTVVPM	Before	13,544	1,071.8	.91084	- 0 -
		After	12,472	906.69	.97387	0.000

+ : - 0 - means that the F significance level << 0.001.

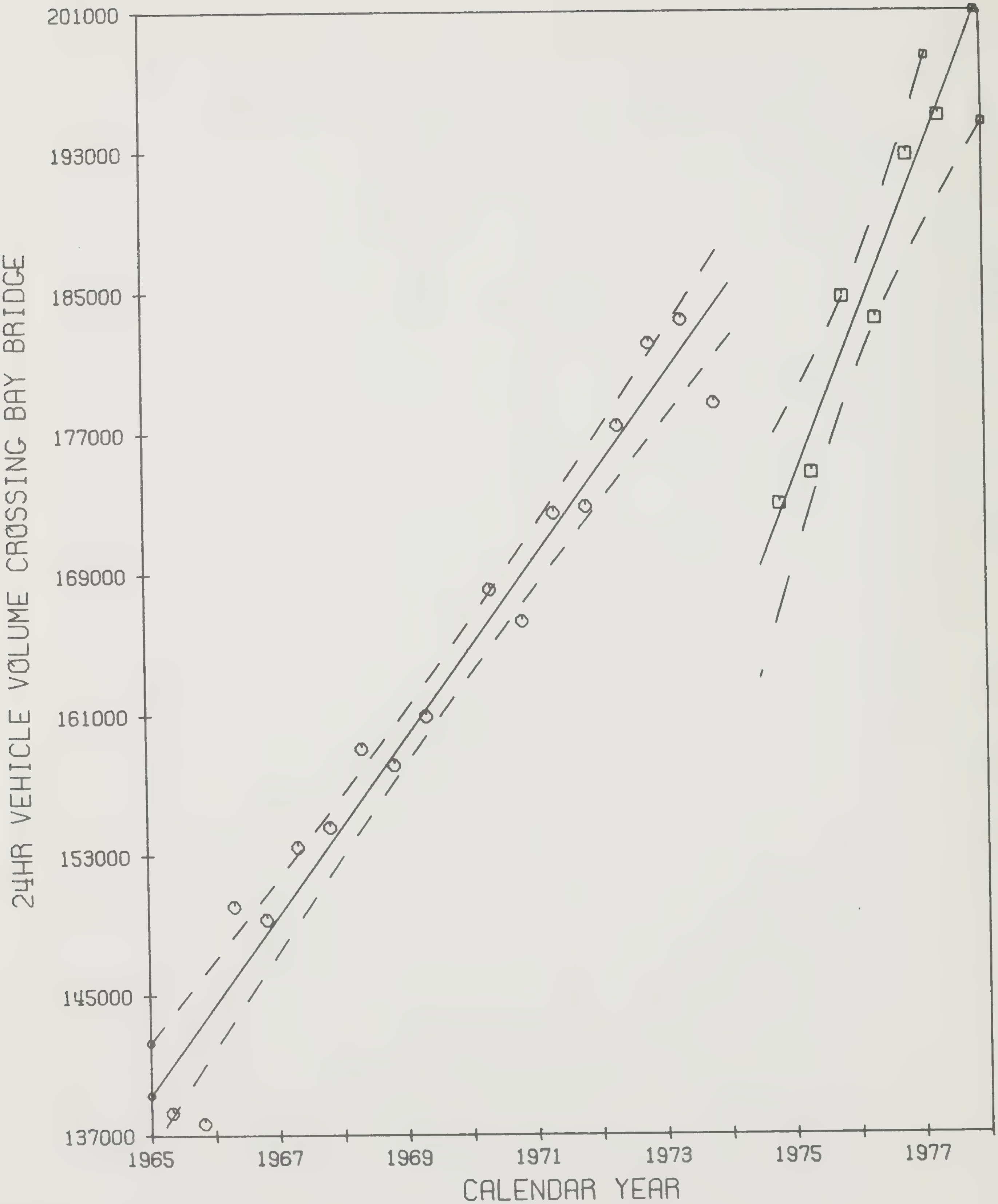

FIGURE 3

TRENDS IN TOTAL 24-HOUR VEHICLE TRAFFIC ACROSS THE BAY BRIDGE.

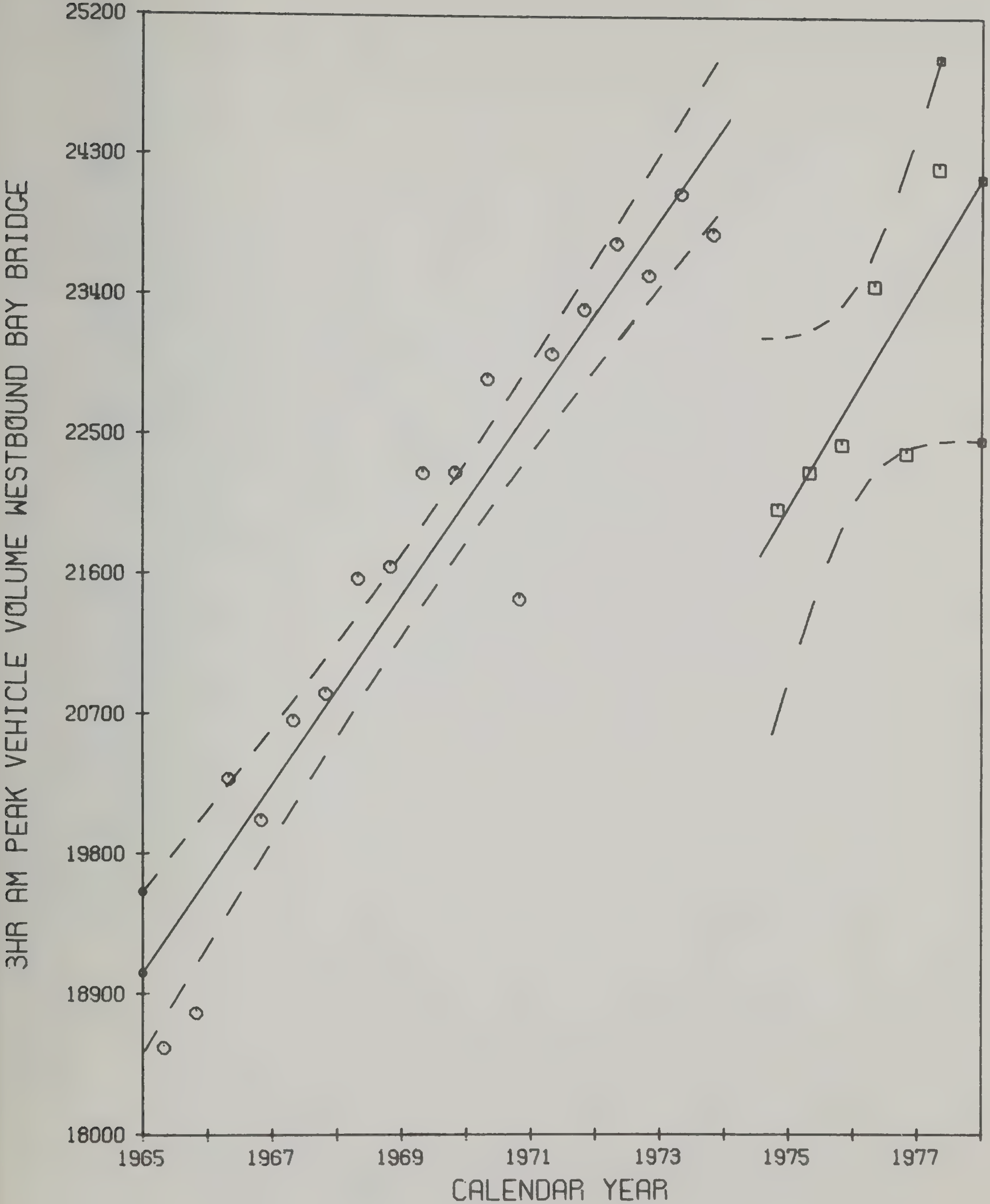

FIGURE 4

TRENDS IN WESTBOUND MORNING PEAK PERIOD VEHICLE TRAFFIC ACROSS THE BAY BRIDGE

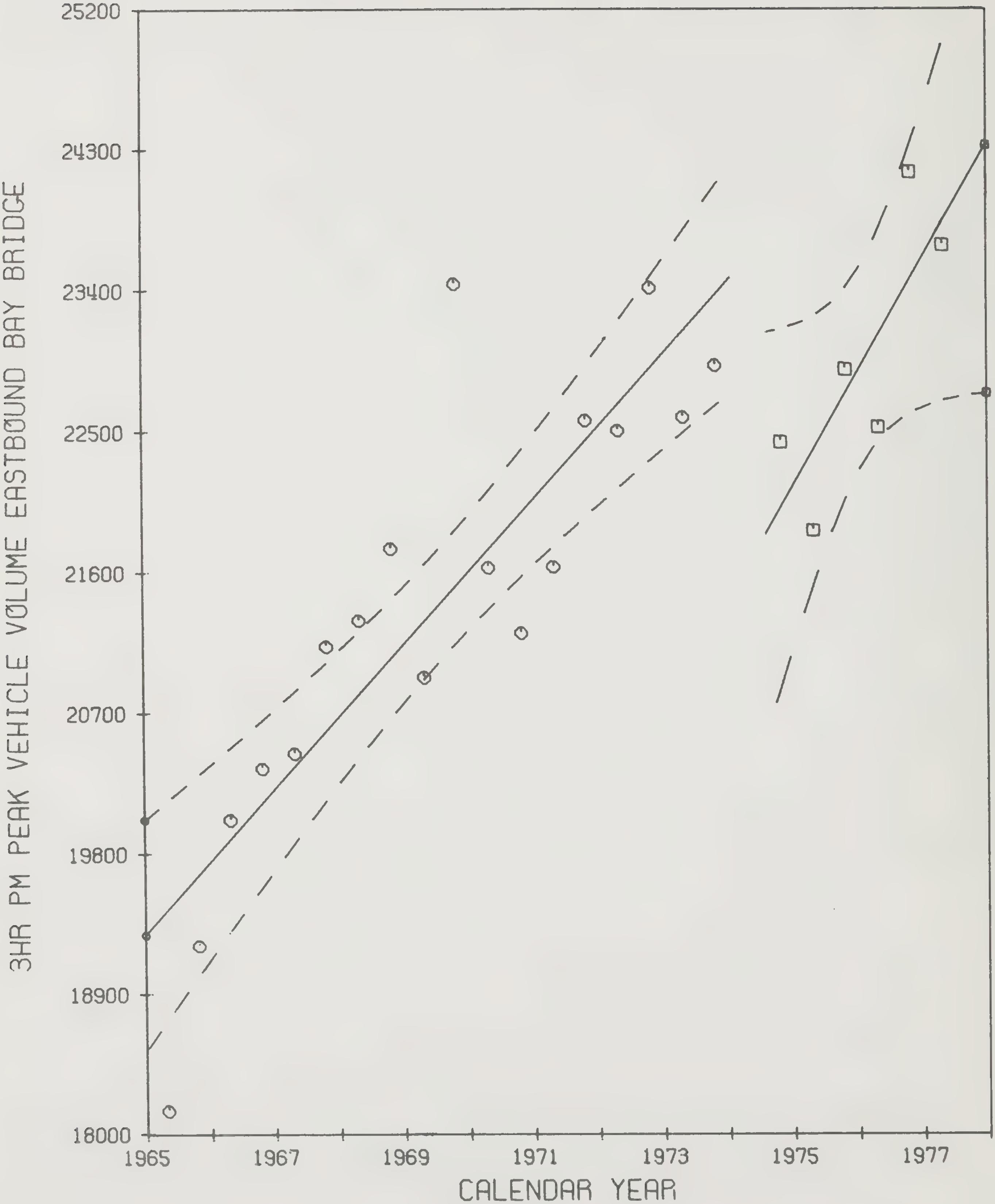

FIGURE 5

TRENDS IN EASTBOUND AFTERNOON PEAK PERIOD VEHICLE TRAFFIC ACROSS THE BAY BRIDGE

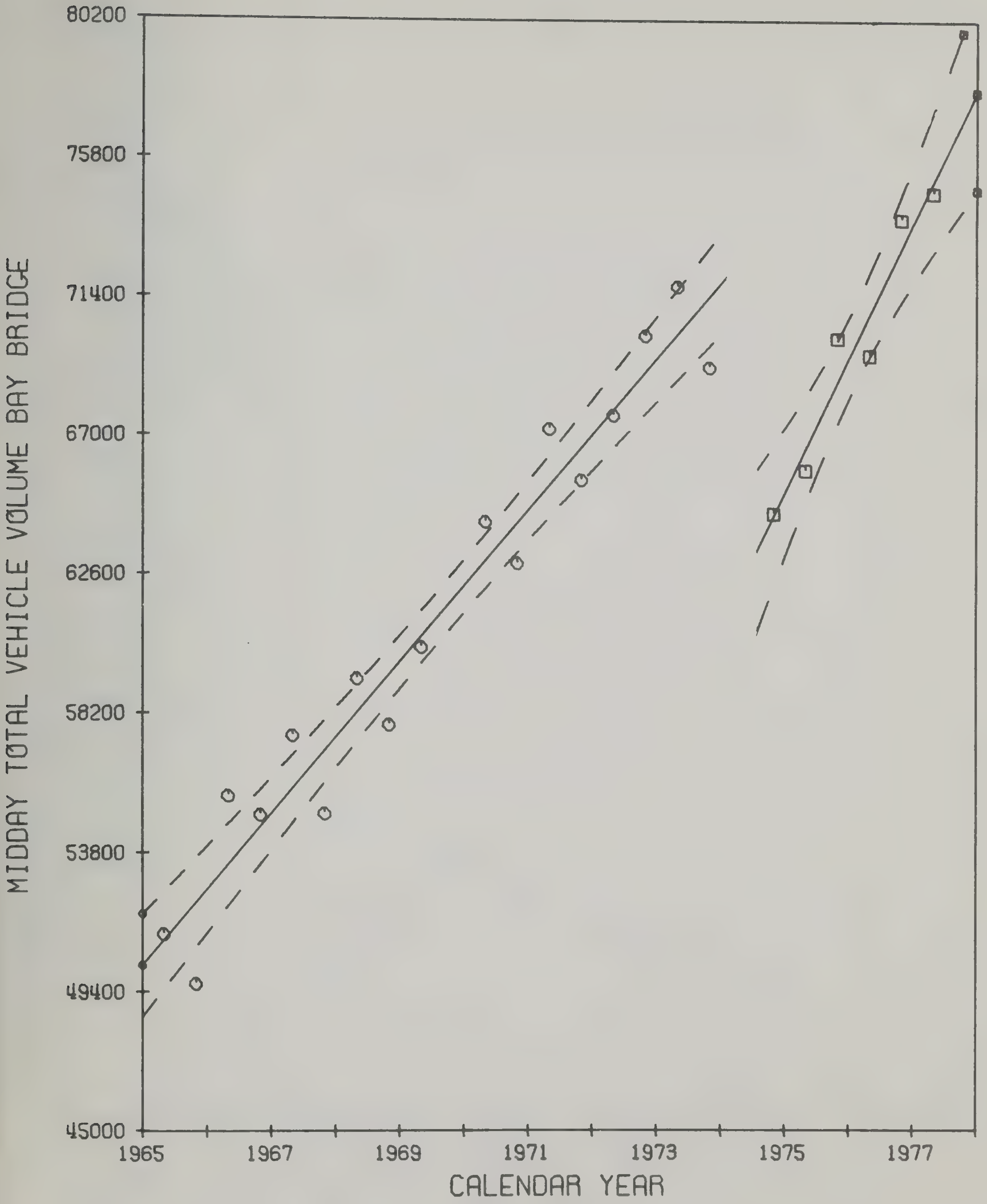

FIGURE 6

TRENDS IN TOTAL VEHICLE TRAFFIC BETWEEN 0900 AND 1600
ACROSS THE BAY BRIDGE.

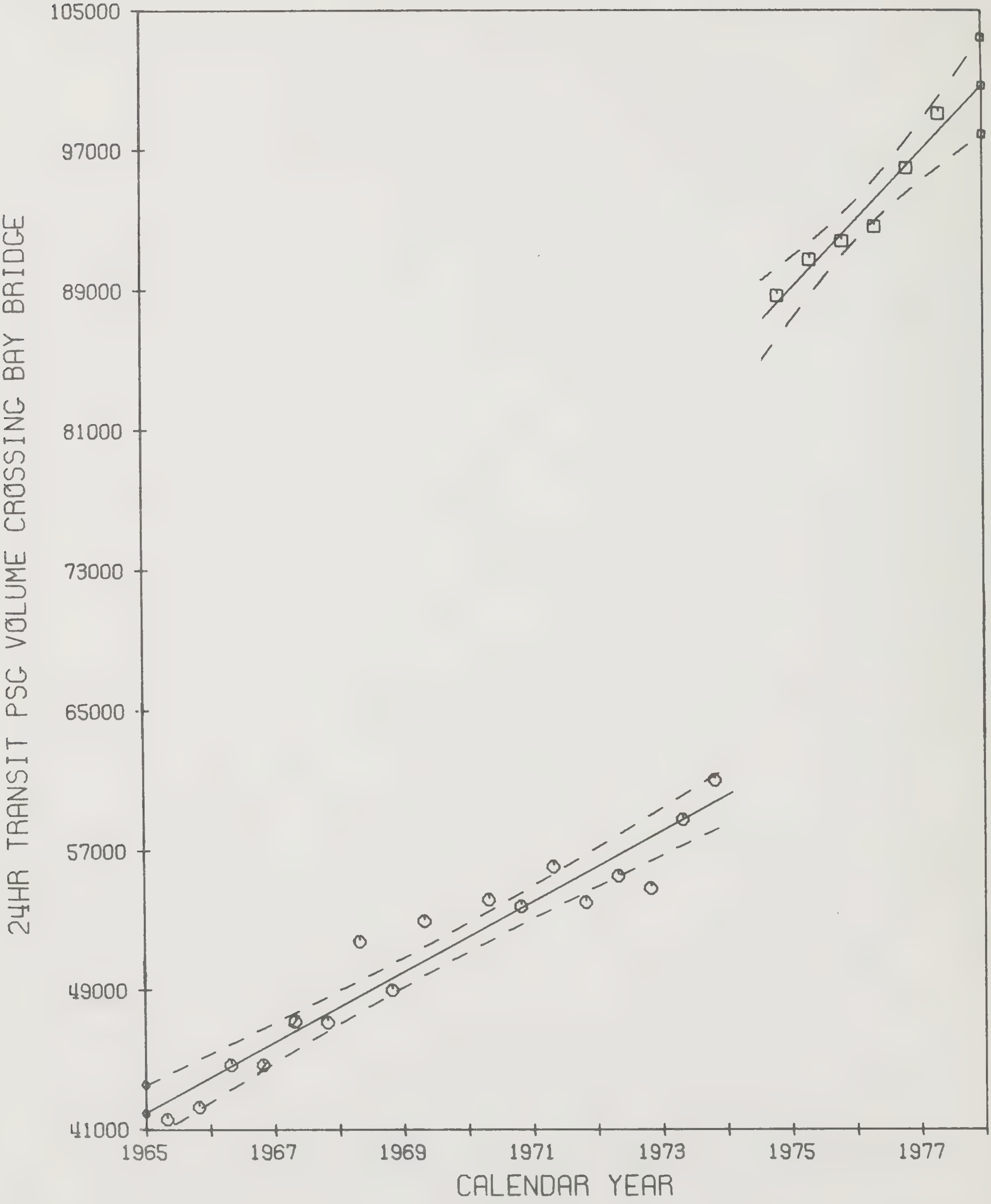

FIGURE 7

TRENDS IN TOTAL 24-HOUR TRANSBAY TRANSIT PASSENGER TRAVEL.

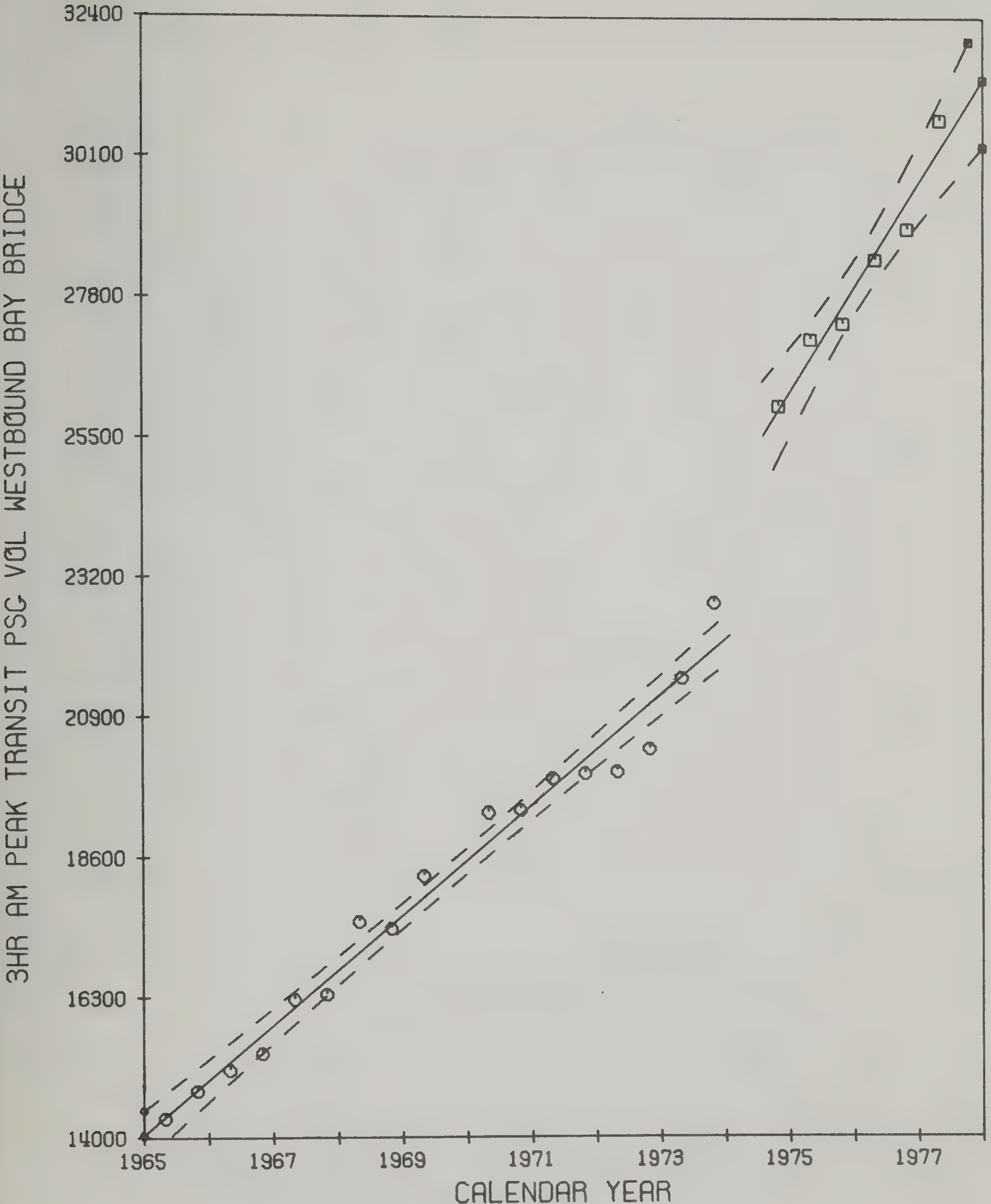

FIGURE 8

TRENDS IN WESTBOUND MORNING PEAK PERIOD
TRANSBAY TRANSIT PASSENGER TRAVEL.

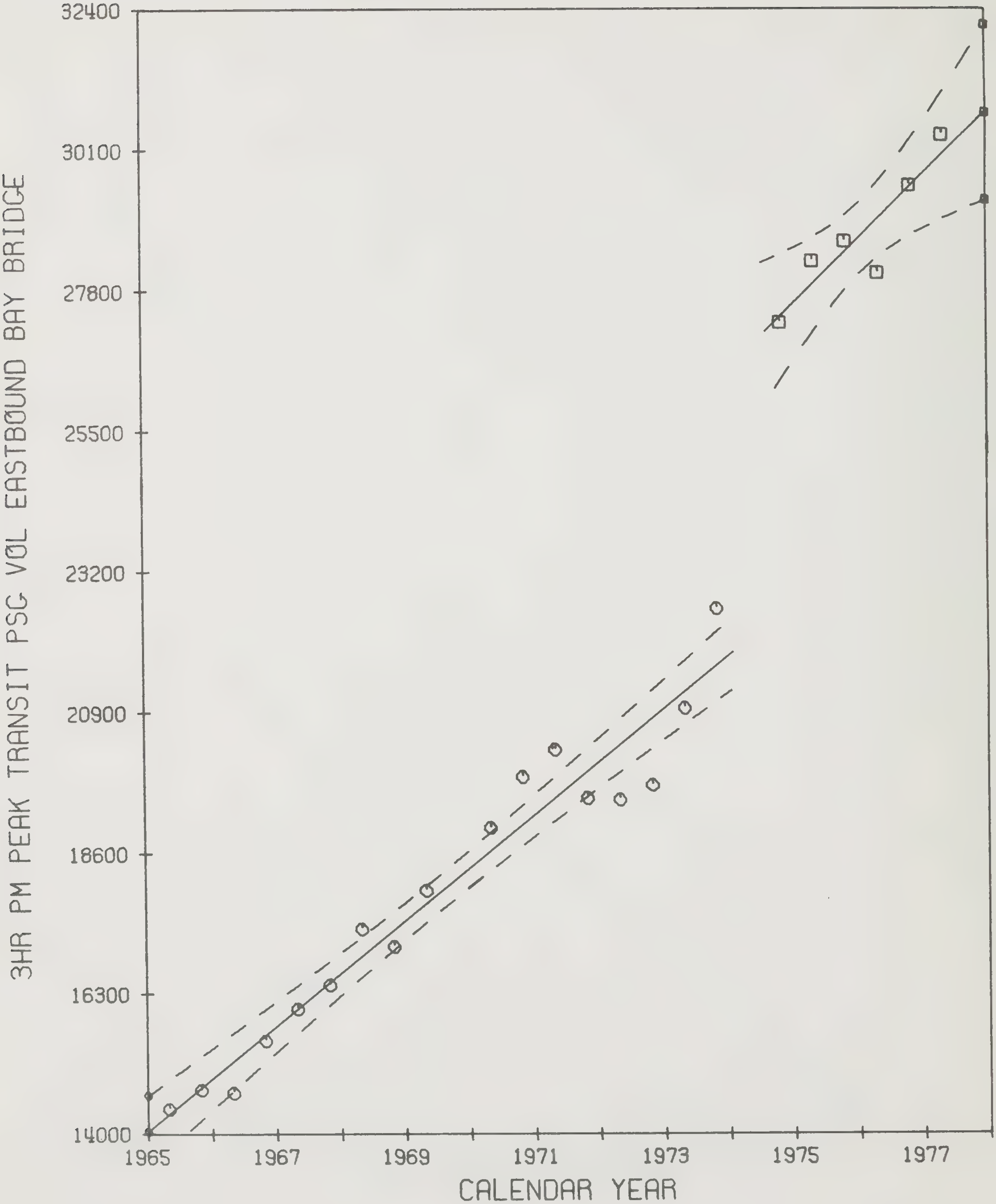

FIGURE 9

TRENDS IN EASTBOUND AFTERNOON PEAK PERIOD
TRANSBAY TRANSIT PASSENGER TRAVEL.

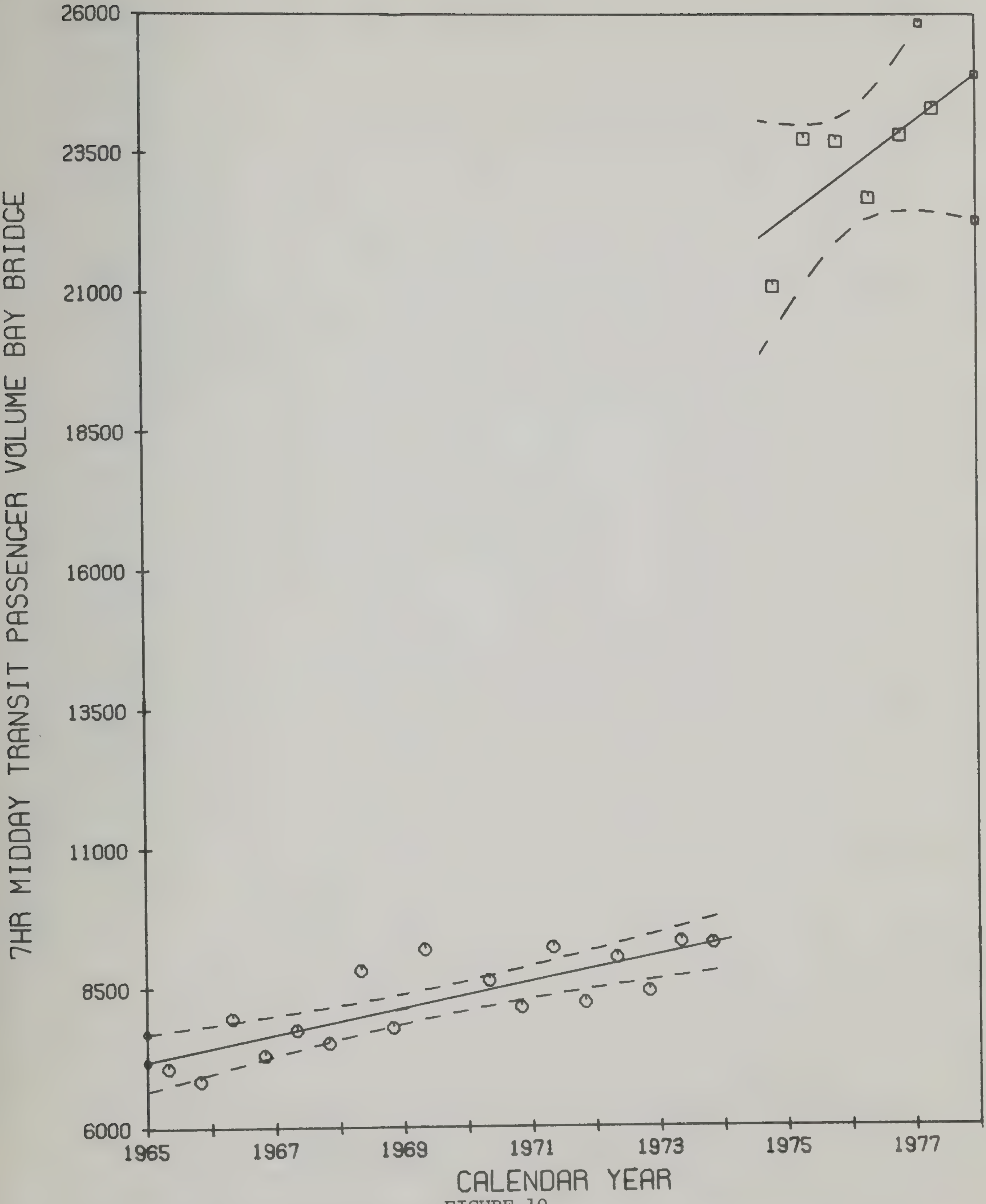

FIGURE 10

TRENDS IN TOTAL TRANSBAY TRANSIT PASSENGER TRAVEL BETWEEN 0900 AND 1600.

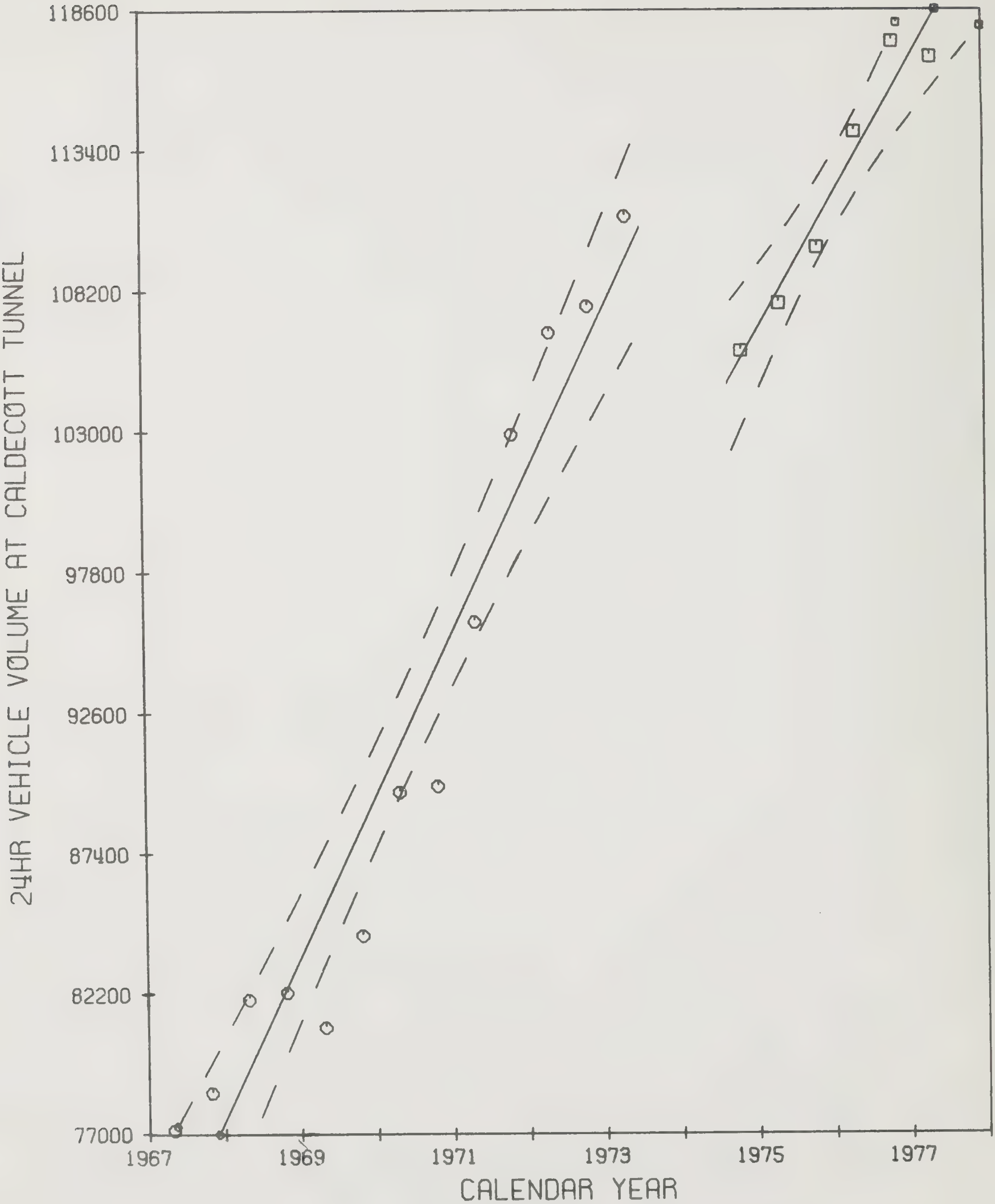

FIGURE 11

TRENDS IN TOTAL 24-HOUR VEHICLE TRAFFIC AT CALDECOTT TUNNEL.

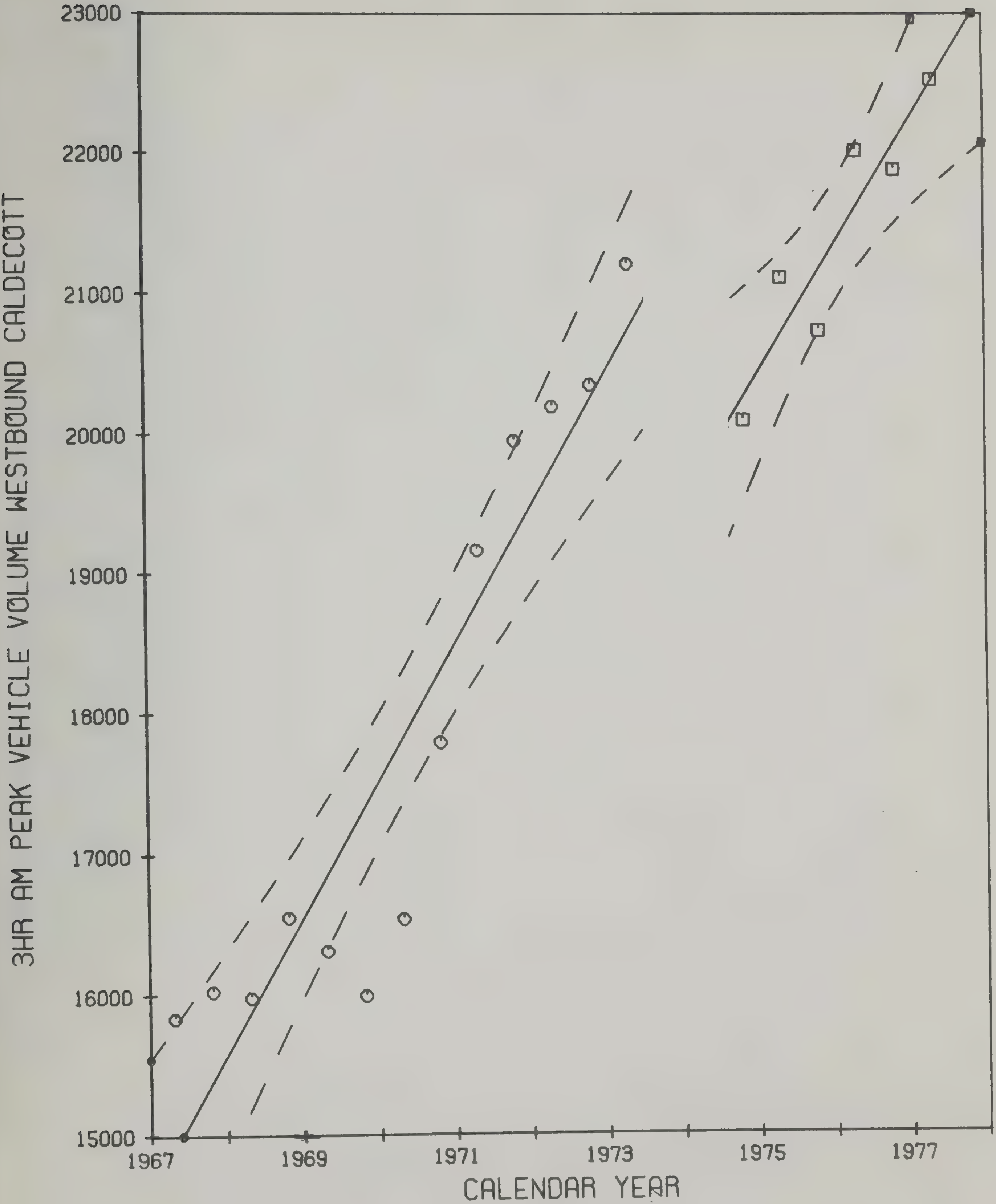

FIGURE 12

TRENDS IN WESTBOUND MORNING PEAK PERIOD
VEHICLE TRAFFIC AT CALDECOTT TUNNEL.

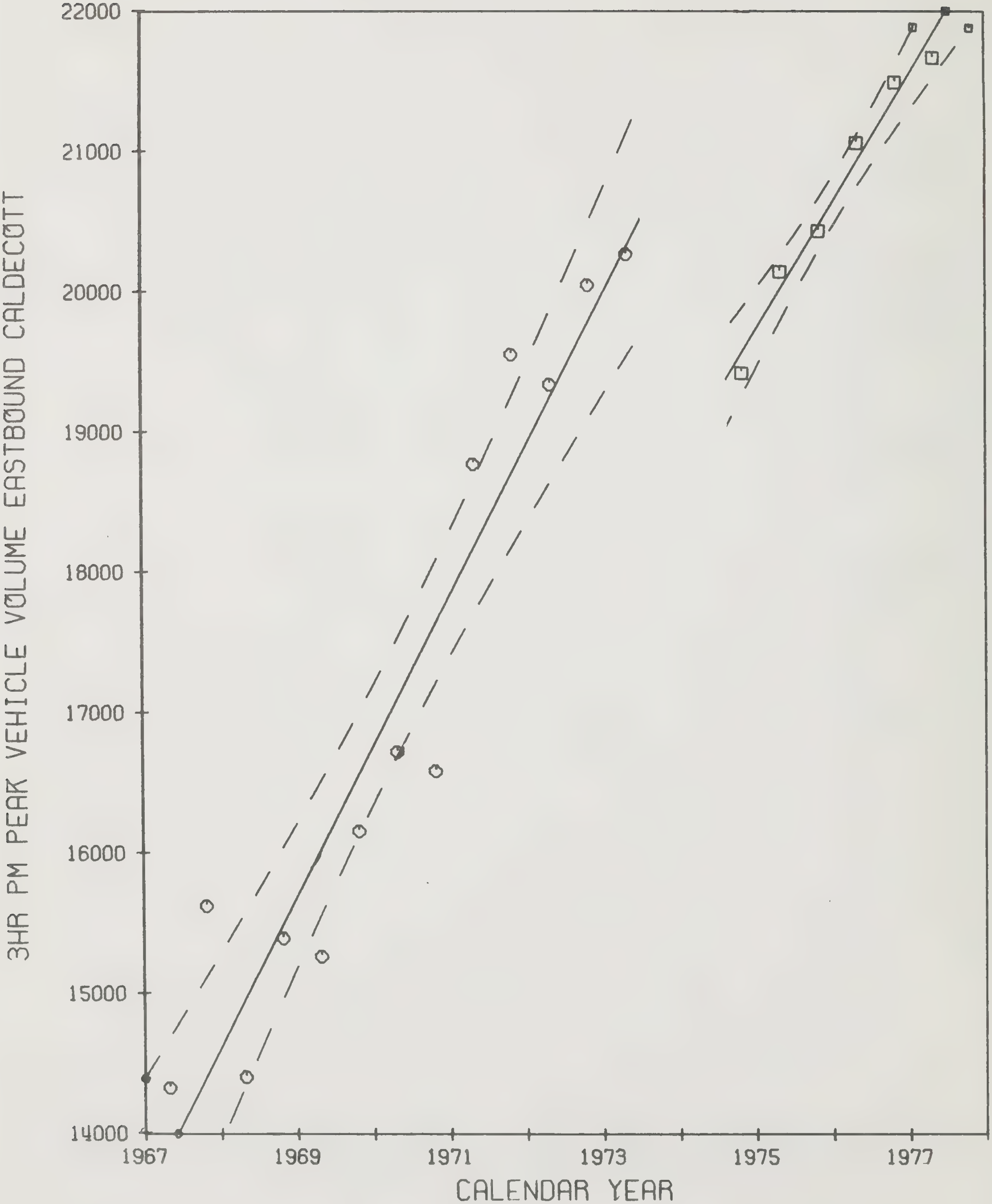

FIGURE 13

TRENDS IN EASTBOUND AFTERNOON PEAK PERIOD
VEHICLE TRAFFIC AT CALDECOTT TUNNEL.

Another study[8], which used midweek traffic volumes for the entire year, and compared Bay Bridge traffic to that of three adjacent toll bridges, finds that the cost of gasoline may have been the primary cause for the drop in vehicle traffic on the Bay Bridge in 1974. The argument is made that a "shortfall" of traffic (a slowing down of a previously observed growth trend adjusted for seasonal variations) began on all four bridges in 1973. Since BART had no impact on the other three bridges (Golden Gate, San Mateo-Hayward, and Richmond-San Rafael), a common cause was sought to explain this phenomenon, and the sudden rise in gasoline prices was selected. However, an equally plausible factor could be the end of steady population growth in San Francisco, Alameda, and Contra Costa counties (see Appendix B) and in Marin County in 1972. The traffic trends on the Bay Bridge correlate with population growth much more closely than with fuel costs. One might also attribute some of the traffic shortfall on the Golden Gate Bridge to a 50% toll increase which took place on March 1, 1974 and which, therefore, detracts from the usefulness of that bridge as a "control" location. Some of the shortfall on the San Mateo bridge may possibly be connected with BART, if some commuters shifted from that bridge to the Bay Bridge after the latter was relieved of some peak period traffic in the Fall of 1974.

Assuming then, that the population trends explain the major component of the slowing down of vehicle volume growth on, among others, the Bay Bridge, a reason must still be found for the discontinuity in the trend lines reported in this study. It is believed that the opening of the BART transbay link was the primary reason for this phenomenon. Only a finegrained study of traffic in the 1973-1975 period might determine whether the rise in fuel costs contributed secondarily to this discontinuity. However, the steeper "catch-up" slopes reported in the post-BART trend lines at the Bay Bridge make it appear unlikely that fuel cost increases could have had more than a very temporary effect.

4.4 Further Analysis of discontinuity in transbay traffic trends

The change in transbay traffic in 1974 is here analyzed by extrapolating the pre-BART trend lines to Fall 1974 and comparing the values thus obtained

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[8] Sherret, Alistair, and Henry Fan. BART Impacts on Highway Traffic and Transit Ridership. Berkeley, Ca.: Metropolitan Transportation Commission. (BART Impact Program.) May 1976.

to those on the post-BART trend lines. The results of these computations are summarized in Table 7. Total person trips in the Fall of 1974 were roughly the same as they might have been projected from the pre-BART data for the 24-hour totals and the 0900-1600 period. The changes in the person trips in the peak periods are also quite small. The important conclusion from the data in Table 7 is that mass transit share of total person trips had increased from 19 to 27% for the entire day, from 39 or 40% to 46 or 47% in the two peaks, and from 9 to 21% in the midday period between the peaks. The immediate (i.e., one month after opening of the transbay BART line) impact of BART was therefore a substantial change in modal split. As the post-BART trend lines are extended in future surveys, it will be seen whether these modal shares remain at their new levels or change in either direction.

5. Analysis of the Shape of the Peak Period Curves

It has been hypothesized that peak period capacity constraints shift some demand temporally. If demand exceeds capacity at the "peak of the peak," some trips will be forced backward or forward in time, spreading the length of the peak. Conversely, one may postulate that an increase in capacity or a reduction in demand would induce the opposite tendency. The inauguration of BART service was such an event: it reduced demand for highway capacity by diverting some travelers to the BART trains, and it may have increased highway capacity by reducing the proportion of buses in the traffic stream.

To investigate this hypothesis, six-minute interval traffic counts from surveys made during a period of about 2 years before and after the opening of BART were compared. The details of the data sets included were described previously in section 3.2. Table 8 and Figures 14-17 summarize and illustrate these comparisons. The indicated levels of statistical significance were computed by using the t test with the means and standard deviations of the six-minute intervals in the "before" and "after" samples consisting of from eight to eleven different days in each sample.

The analysis proves the time-shift hypothesis quite clearly for the early part of the morning peak at both locations. At the Bay Bridge, average total vehicle flow between 0600 and 0630 dropped 840 vehicles or 29% after the BART opening, and the following half hour experienced a reduction of almost 300 vehicles or 7%. For the first 42 minutes of this hour the drop in traffic is highly significant statistically. At Caldecott Tunnel, traffic reduction amounted

TABLE 7 -- EXTRAPOLATION OF PRE-BART TRENDS TO FALL 1974 AND COMPARISON WITH POST-BART TREND LINES, TRANSBAY TRAFFIC

	Both Directions 24 Hours	Westbound Three-Hour Morning Peak	Eastbound Three-Hour Afternoon Peak	Both Directions 0900-1600
Pre-BART Trends Extrapolated				
Vehicle traffic	189,600	25,000	23,800	73,800
Person trips in motor vehicles*	260,600	35,100	34,000	97,900
Person trips on mass transit	61,800	22,900	22,500	9,500
Total person trips	322,400	58,000	56,500	107,400
Proportion on transit	19%	39%	40%	9%
Post-BART Trend Line Values				
Vehicle traffic	172,300	21,900	22,000	64,500
Person trips in motor vehicles*	236,900	30,700	31,500	85,600
Person trips on mass transit	88,300	26,000	27,400	22,200
Total person trips	325,200	56,700	58,900	107,800
Proportion on transit	27%	46%	47%	21%
Change in person trips	+2,800 (+0.9%)	-1,300 (-2.3%)	+2,400 (+4.2%)	-400 (-0.4%)
Change in proportion on mass transit	+8%	+7%	+7%	+12%

*Excludes buses

TABLE 8 - CHANGES IN SIX-MINUTE VEHICULAR TRAFFIC FLOW

PART A - Morning Peak Period

TIME	BAY BRIDGE					CALDECOTT TUNNEL				
Six Mins. From	Traffic Flow		Change in Flow		Level of Signif-icance	Traffic Flow		Change in Flow		Level of Signif-icance
	Before	After	Number	%		Before	After	Number	%	
0600	403	295	-108	-26.8	0.1%	261	202	- 59	-22.6	5%
0606	482	324	-158	-32.8	0.1%	326	269	- 57	-17.5	NS
0612	584	394	-190	-32.6	0.1%	446	344	-102	-22.9	1%
0618	675	484	-191	-28.3	0.1%	502	413	- 89	-17.7	0.1%
0624	753	560	-193	-25.6	0.1%	555	488	- 67	-12.1	2%
0630	808	677	-131	-16.2	0.1%	633	586	- 47	- 7.4	NS
0636	832	741	- 92	-11.0	0.1%	683	673	- 10	- 1.5	NS
0642	829	785	- 44	- 5.3	NS	710	728	+ 18	+ 2.5	NS
0648	860	852	- 8	- .9	NS	729	778	+ 49	+ 6.7	5%
0654	853	834	- 19	- 2.2	NS	735	766	+ 31	+ 4.2	NS
0700	914	958	+ 45	+ 4.9	NS	751	807	+ 56	+ 7.5	NS
0706	891	937	+ 46	+ 5.1	NS	750	794	+ 44	+ 5.9	NS
0712	921	932	+ 11	+ 1.2	NS	746	808	+ 62	+ 8.3	1%
0718	902	932	+ 30	+ 3.3	NS	737	822	+ 85	+11.5	0.1%
0724	863	898	+ 35	+ 4.0	NS	736	811	+ 75	+10.2	0.1%
0730	856	926	+ 69	+ 8.1	NS	753	850	+ 97	+12.9	0.1%
0736	858	915	+ 57	+ 6.7	NS	750	839	+ 89	+11.9	0.1%
0742	835	903	+ 68	+ 8.1	NS	730	832	+102	+14.0	0.1%
0748	827	877	+ 50	+ 6.0	NS	760	843	+ 83	+10.9	0.1%
0754	794	821	+ 27	+ 3.4	NS	743	826	+ 83	+11.2	0.1%
0800	837	891	+ 54	+ 6.5	NS	720	839	+119	+16.5	0.1%
0806	807	856	+ 49	+ 6.1	2%	747	827	+ 80	+10.7	2%
0812	807	849	+ 41	+ 5.1	NS	730	813	+ 83	+11.4	1%
0818	786	816	+ 30	+ 3.8	NS	721	783	+ 62	+ 8.6	NS
0824	743	781	+ 38	+ 5.1	NS	702	765	+ 63	+ 9.0	NS
0830	747	793	+ 45	+ 6.1	5%	625	700	+ 75	+12.0	NS
0836	761	801	+ 40	+ 5.2	NS	594	673	+ 79	+13.3	NS
0842	744	759	+ 15	+ 2.0	NS	555	653	+ 98	+17.7	NS
0848	715	731	+ 16	+ 2.3	NS	549	622	+ 73	+13.3	NS
0854	666	674	+ 9	+ 1.3	NS	468	542	+ 74	+15.8	5%
Total	23354	22994	-360	- 1.5	NS	19447	20696	+1249	+ 6.4	NS

NS = Not significant at the 5% level

Numbers may not add because of rounding

TABLE 8 (continued)

PART B - Afternoon Peak Period

TIME	BAY BRIDGE					CALDECOTT TUNNEL				
Six Mins. From	Traffic Flow		Change in Flow		Level of Signif-icance	Traffic Flow		Change in Flow		Level of Signif-icance
	Before	After	Number	%		Before	After	Number	%	
1600	827	819	- 8	- 1.0	NS	528	571	+ 43	+ 8.1	5%
1606	835	801	- 34	- 4.1	NS	570	635	+ 65	+11.4	1%
1612	871	776	- 95	-11.0	0.1%	626	718	+ 92	+14.7	0.1%
1618	850	875	+ 25	+ 2.9	NS	656	691	+ 35	+ 5.3	5%
1624	834	853	+ 19	+ 2.3	NS	611	679	+ 68	+11.1	0.1%
1630	850	824	- 26	- 3.1	NS	663	709	+ 46	+ 6.9	2%
1636	862	829	- 34	- 3.9	NS	700	773	+ 73	+10.4	0.1%
1642	882	813	- 69	- 7.9	1%	727	762	+ 35	+ 4.8	NS
1648	921	835	- 86	- 9.4	5%	746	762	+ 16	+ 2.1	NS
1654	902	864	- 39	- 4.3	NS	733	764	+ 31	+ 4.2	2%
1700	817	864	+ 46	+ 5.6	NS	727	779	+ 52	+ 7.2	0.1%
1706	806	838	+ 32	+ 3.9	NS	717	791	+ 74	+10.3	2%
1712	806	817	+ 11	+ 1.3	NS	717	746	+ 29	+ 4.0	NS
1718	840	822	- 18	- 2.2	NS	742	769	+ 27	+ 3.6	0.1%
1724	811	871	+ 60	+ 7.4	2%	704	756	+ 52	+ 7.4	NS
1730	785	842	+ 57	+ 7.2	NS	735	773	+ 38	+ 5.2	5%
1736	805	813	+ 8	+ 1.1	NS	733	749	+ 16	+ 2.2	NS
1742	767	789	+ 21	+ 2.8	NS	697	758	+ 61	+ 8.8	0.1%
1748	797	769	- 29	- 3.6	NS	656	758	+102	+15.5	0.1%
1754	747	726	- 21	- 2.8	NS	634	711	+ 77	+12.1	5%
1800	735	705	- 30	- 4.1	NS	623	652	+ 29	+ 4.7	NS
1806	725	707	- 18	- 2.4	NS	575	597	+ 22	+ 3.8	NS
1812	715	699	- 16	- 2.2	NS	548	566	+ 18	+ 3.3	NS
1818	691	647	- 44	- 6.4	NS	538	541	+ 3	+ 0.6	NS
1824	649	631	- 18	- 2.8	NS	465	489	+ 24	+ 5.2	NS
1830	594	650	+ 56	+ 9.4	NS	430	498	+ 68	+15.8	NS
1836	554	597	+ 43	+ 7.8	NS	394	405	+ 11	+ 2.8	NS
1842	482	580	+ 97	+20.2	1%	368	398	+ 30	+ 8.2	NS
1484	505	558	+ 53	+10.5	NS	347	366	+ 19	+ 5.5	NS
1854	491	541	+ 50	+10.1	NS	304	347	+ 43	+14.1	5%
Total	22761	22754	- 8	-0.04	NS	18214	19513	+1299	+ 7.1	NS

NS = Not significant at the 5% level

Numbers may not add because of rounding

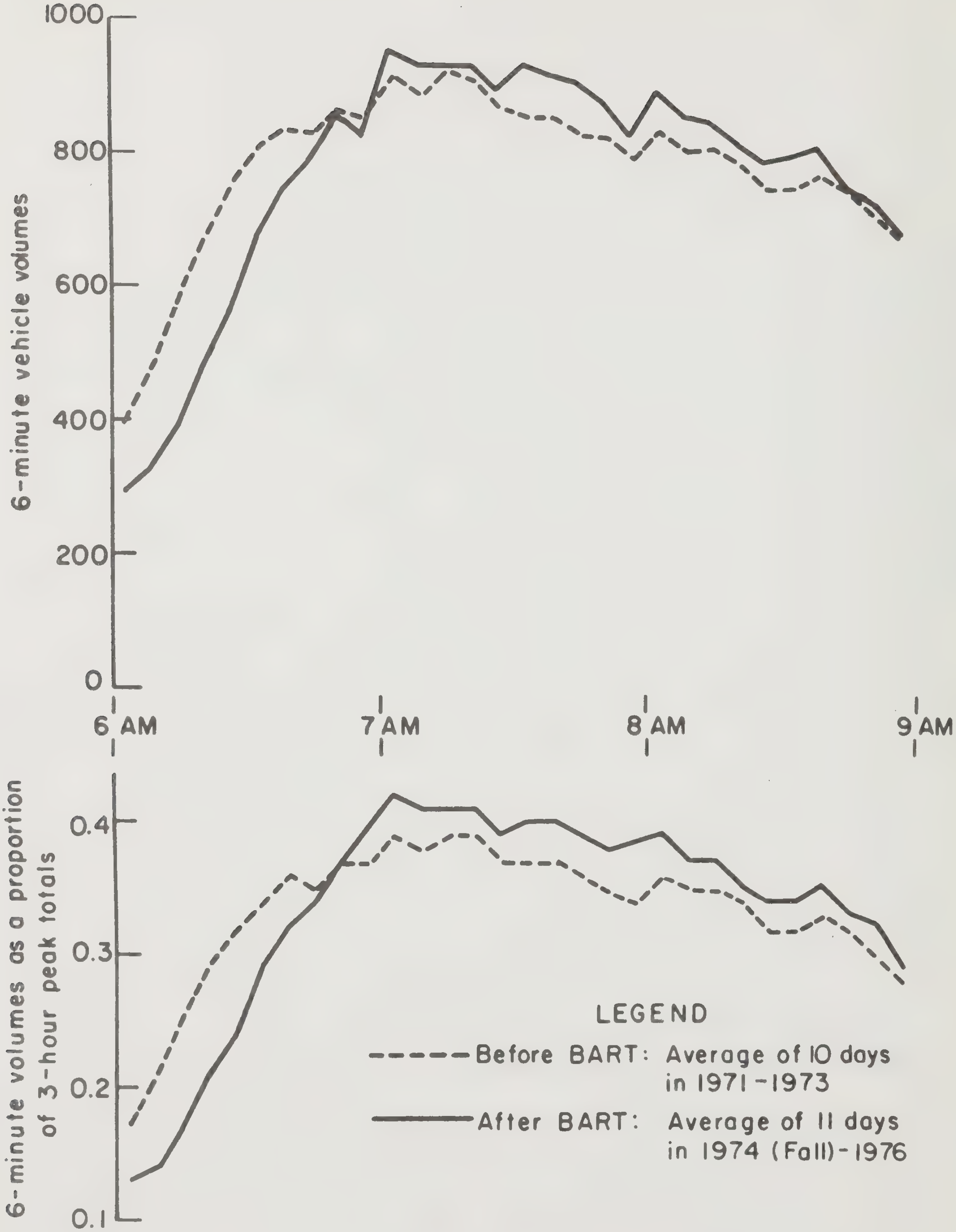

FIGURE 14

SIX-MINUTE VEHICLE VOLUMES IN THE WESTBOUND MORNING PEAK ACROSS THE BAY BRIDGE BEFORE AND AFTER BART.

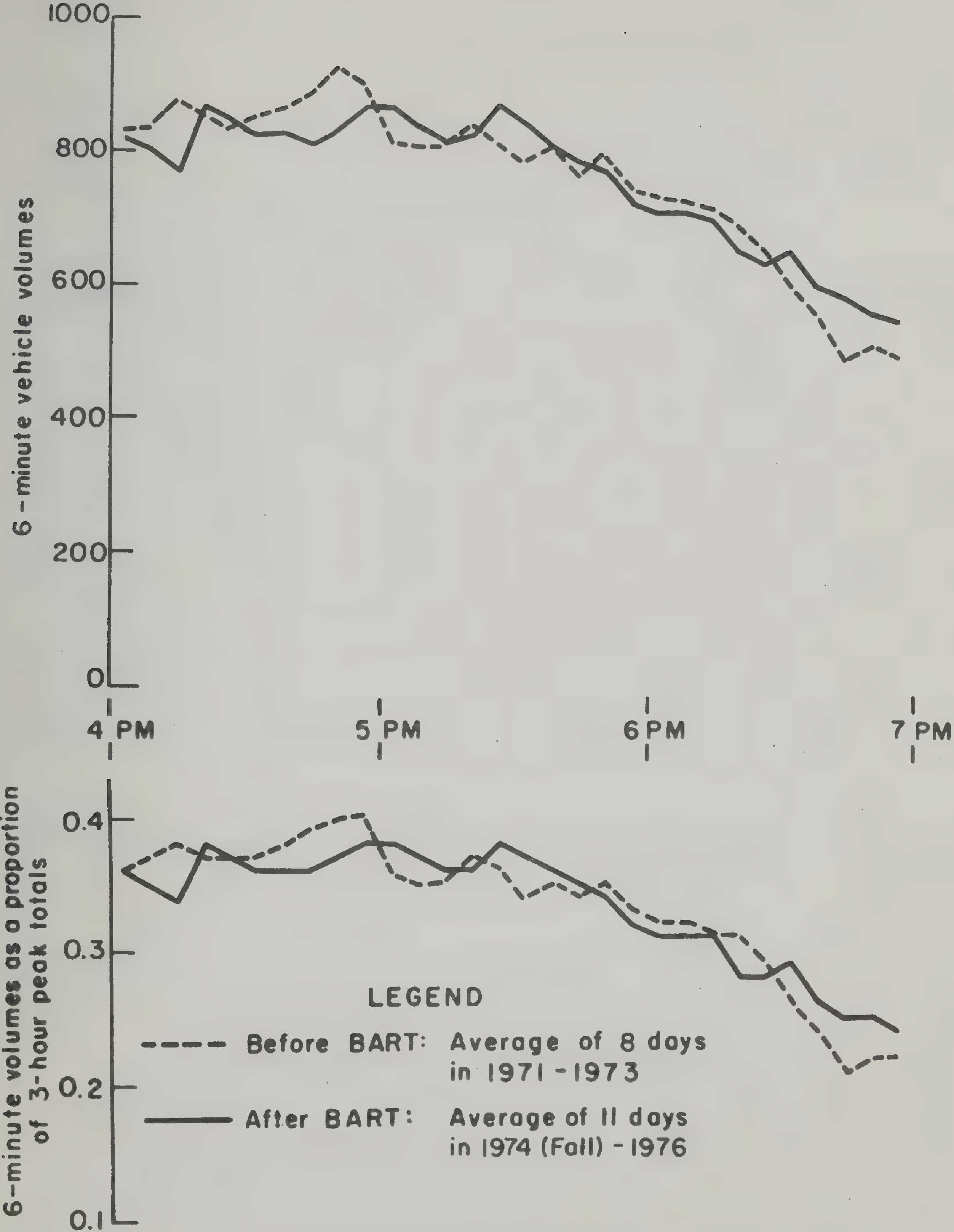

FIGURE 15

SIX-MINUTE VEHICLE VOLUMES IN THE EASTBOUND AFTERNOON PEAK ACROSS THE BAY BRIDGE BEFORE AND AFTER BART.

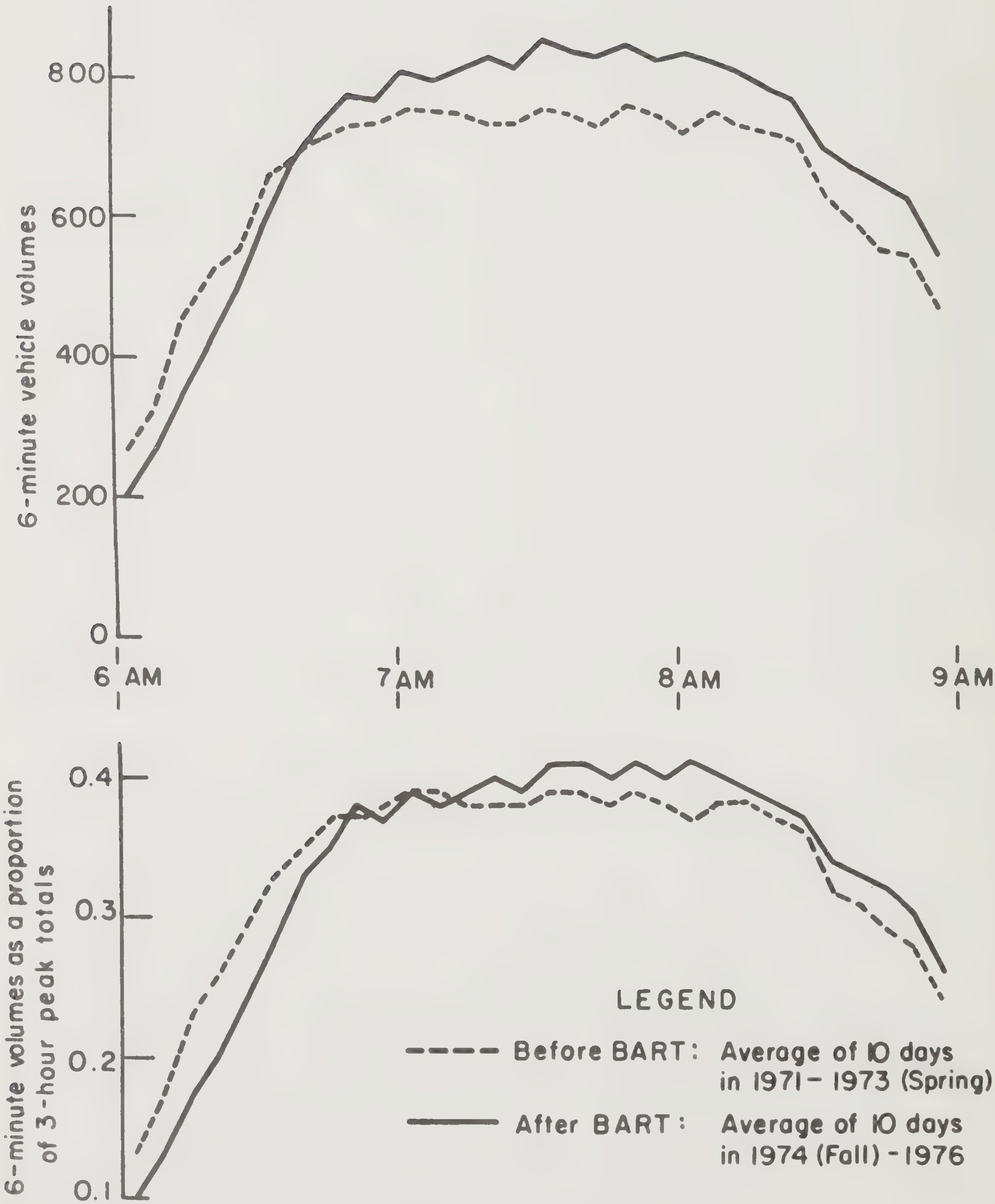

FIGURE 16

SIX-MINUTE VEHICLE VOLUMES IN THE WESTBOUND MORNING PEAK AT CALDECOTT TUNNEL BEFORE AND AFTER BART.

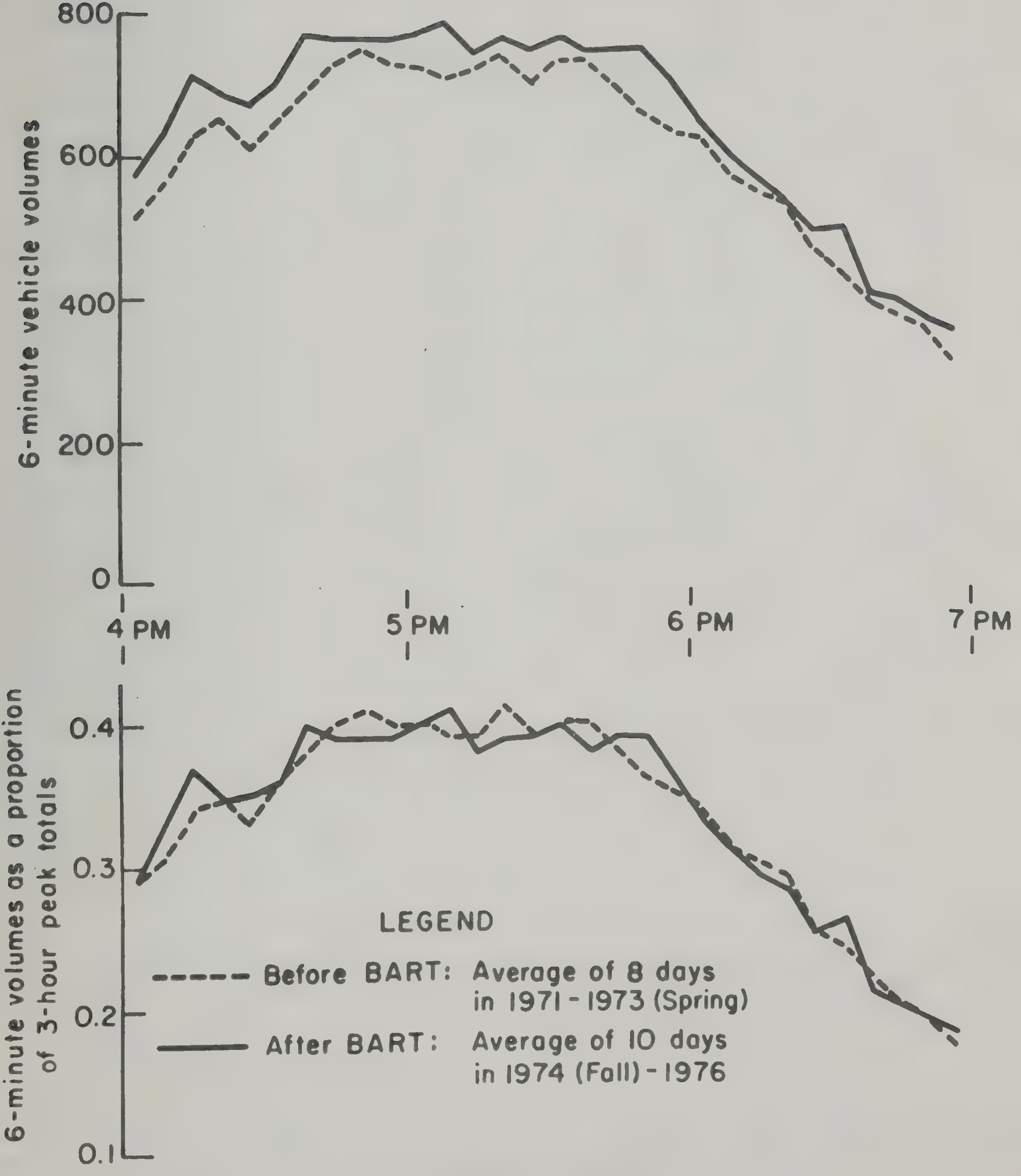

FIGURE 17

SIX-MINUTE VEHICLE VOLUMES IN THE EASTBOUND AFTERNOON PEAK AT CALDECOTT TUENNEL BEFORE AND AFTER BART.

to about 375 vehicles or 18% between 0600 and 0630, but in view of greater variations between individual counts, the statistical significance of this phenominon is not consistently high. In the next half hour the traffic reduction becomes a traffic increase.

None of the other three "shoulders" of the peaks, late morning, or early or late afternoon, produced comparable results. Traffic at the end of both peaks increased at both locations. At the beginning of the afternoon peak only Bay Bridge flows dropped, and even this reduction was modest and generally not statistically significant.

An important finding of this part of the study is the increase in traffic flow during the center of the peaks at both locations. One would have hypothesized that BART would reduce peak flow generally, and that the capacity of the two facilities, which was being fully utilized before BART, would remain the same. It will be noted however, that traffic flow increased consistently between 0700 and 0830 at both locations, and throughout the evening 3-hour peak period at Caldecott Tunnel. At the latter facility, the increase in traffic is statistically significant in many six-minute intervals; particularly remarkable is the highly significant increase from 0718 to 0806 westbound, and the occasionally high levels of significance before 1800 eastbound.

These figures imply, of course, that capacity at the Caldecott Tunnel and, to a lesser extent at the Bay Bridge, increased after the introduction of BART. The only causes of such an increase which come to mind are the reduction in the proportion of buses in the traffic streams and, at the Bay Bridge westbound, the introduction of metering the approach lanes. The latter, according to CALTRANS officials familiar with the project, may have had a small effect in that it permits trucks and buses to reach the beginning of the long 3% upgrade of the bridge at full speed rather than at a crawl. However, it is not considered likely that this would add more than one or two percent to the bridge's capacity.

The drop in bus traffic is explored further in Appendix C. The table is relegated to an appendix to underline the speculative nature of the contents and the relatively weak condition of the underlying data. The difference in bus and heavy truck traffic is obtained only once per survey; hence while the total traffic change is computed from samples of eight to eleven days, the bus and truck data are averages of only four days. The large fluctuations in truck traffic from one survey to the next add to the doubts one must have about the accuracy of the calculations.

Nevertheless, a plausible explanation of the increased capacity of the Caldecott Tunnel can be postulated. The approaches to the tunnel consist of long stretches of uphill roadway -- 2.2 miles at an average grade of 4.6% westbound and 1.7 miles at 5.5% eastbound. Drivers noticing a bus or heavy truck in the shoulder lane ahead of them know the reduced speed at which these vehicles climb toward the tunnel. They therefore change to another lane at the earliest opportunity. The shoulder lane then operates well below capacity.

In the westbound direction, an auxiliary lane was added to the roadway from the Gateway Boulevard Interchange (1 mile east of the tunnel) to the Fish Ranch Road exit just ahead of the portal in the fall of 1972. There are not sufficient data between this event and the staged opening of BART to analyze the impact of this action on westbound capacity, but a review of peak period traffic totals which are available implies that this action may have increased the capacity of the westbound approach by 200 vehicles in the peak half hour. In January 1974 additional striping changes were made in the west approach, but the maximum traffic flow rates recorded in the count prior to and the one after this event are almost identical; therefore this action has been ignored in this discussion.

Eastbound conditions differ from the westbound ones in that the entire length of the uphill approach is used by less than 75% of the tunnel traffic; the remainder enters the highway at a ramp just before the tunnel portal. If drivers coming on the main freeway tended to shun the shoulder lane when noticing heavy vehicles ahead, as discussed earlier, this action would increase the capacity of the on-ramp near the tunnel.

While buses are generally considered to be equivalent to 1.6 passenger cars on level roads, this capacity-related parameter varies with the length and steepness of grades, as it does for trucks. The numbers derived in Appendix B -- a bus equivalence of around 7 passenger cars -- is in the realm of possibility.

At the Bay Bridge, where the increases in peak traffic flows are smaller and statistically less significant, the westbound capacity may nevertheless have been influenced in a similar way. In the eastbound direction, traffic is measured after it has passed several permanent bottlenecks and been exposed to the possibility of temporary bottlenecks in the form of stalled vehicles. Reliability in capacity flow data from the small sample sizes available can therefore not be expected.

One may conclude from the analysis of the peak period curves that BART did

cause the reduction in bus traffic through the Caldecott Tunnel and across the Bay Bridge, particularly in the peak hour. This, when adjusted for changes in heavy truck traffic, had the effect of making room for from four to eight passenger cars for each heavy vehicle removed, thus increasing the capacity of the Bay Bridge perhaps 6% westbound and 3% eastbound, and that of Caldecott Tunnel by approximately 6% in each direction. This capacity increase was taken up by additional passenger car traffic (which term includes pickup trucks and other light commercial vehicles). In the morning, the reduction in traffic before 0700 was evidently caused by BART, but the direct cause seems to have been the removal of buses from the two facilities rather than the switch of passenger car occupants to BART travel.

6. Summary and Conclusion

6.1 Trend analysis

The investigation of selected traffic trend data for the period from 1965 to 1977 reveals that vehicle volume growth has been relatively constant from year to year, with an interruption in the trend in 1974, when the BART transbay line opened and the temporary fuel shortage and the permanent jump in fuel prices took place. The impact of the fuel situation on vehicle volumes as a separate causative factor is not evident from the statistical analysis. When the data are separated, with those before BART in one group and those from Fall 1974 to the present day in the other, the pre-1974 relationship of the trends with time -- and with trade/finance/service employment or population, which correlate with years up to 1972 -- is seen to be very close. The period after Fall 1974 includes only six sets of counts, and any trend line based on such few points must be viewed cautiously. However, there is a general tendency for the post-BART trend line at the Bay Bridge to begin at a level below that at which the pre-BART line ended and then to climb at a faster rate. This suggests that the opening of BART, with a possible assist from the fuel crisis, temporarily reduced vehicle volumes, but that these are now catching up. In two or three years it may become evident whether growth will return to the old rate; however, new extraneous factors (increase in Bay Bridge tolls, for example) may cause further perturbations in the trends. At Caldecott, "catching up" is not yet evident.

The transbay mass transit passenger trends behaved in a somewhat similar fashion until 1973, generally growing each year. The pattern of growth again

corresponded closely to the number of jobs in employment categories found predominantly in central business districts -- services, trade, financial, insurance and real estate. This is especially true for the trends in peak period commuting patterns. In the pre-BART/post-BART analysis, the post-BART trend line starts at a level higher than that at which the pre-BART line ended, suggesting a one-time jump in transit riding induced by BART. The slope of the post-BART trend line is steeper than that of the pre-BART line, indicating that transit patronage experienced a more permanent gain in 1974 and that the trends will not converge to an extrapolation of the pre-BART trends. Of special interest is the quantum jump in transit riding across the Bay between 0900 and 1600. This had already been obvious as individual traffic counts were made; personal observation indicated that much of the new midday riding consists of sightseers, including classes of school children, shoppers and lunchers.

Rough estimates made of the immediate impact of BART on transbay traffic suggest that total person trips in the Fall of 1974 were roughly the same as would have occurred if the events of 1974 had not taken place. However, the modal share of transit (BART and buses combined) increased from 19 to 27% on a 24-hour basis from 39 or 40% to 46 or 47% in the peak periods, and from 9 to 21% between 0900 and 1600.

6.2 Peak period analysis

The only noticeable and statistically significant changes in peak period vehicular traffic patterns are the reduction in flow rates in the early part of the morning peak both at the Bay Bridge and Caldecott Tunnel, and the increase in flow rates at Caldecott Tunnel in the middle of both peaks. The former phenomenon could easily be hypothesized, since the traffic which disappeared had probably traveled at these early hours against its free will to avoid congestion later; with the removal of some auto traffic in the center of the peak, and with some increase in capacity because of the reduction in bus traffic, these drivers chose to commute somewhat later than before, closer to the optimum time for their journeys.

The increase in traffic in the middle of the peak, especially at the Caldecott Tunnel, indicates an increase in capacity. After allowing for the effect of a new westbound auxiliary lane near the east tunnel portal, the remaining increase and all of the eastbound increase at the tunnel can only be explained by the reduction in bus traffic, as passengers from surface transit lines diverted to BART. As a result, the total 3-hour peak traffic (0600 - 0900 westbound and

1600 - 1900 eastbound) actually increased substantially (7.1%), even though the difference was not highly significant in statistical terms. Perhaps 75% of this increase can be accounted for by a shift of pre-BART Fish Ranch Road traffic into Caldecott Tunnel, so that the net increase in vehicle traffic during the three-hour peaks is truly insignificant in statistical terms. Among the benefits which might therefore be credited to BART is the time savings to those motorists who left home for work unnecessarily early prior to 1974, and time and automobile operating cost savings for some of the 1,000 commuters per day per direction who were able to shift from the Fish Ranch Road to Caldecott Tunnel, thereby saving both travel time and the need to negotiate the crossing of the high pass at Grizzly Peak Boulevard.

ACKNOWLEDGEMENTS

The data files on which this report is based were assembled with the assistance of several agencies, within which many different persons were directly helpful over the years. The agencies include the California Department of Transportation District 4 (including the Bay Toll Crossings Division), the Alameda-Contra Costa Transit District, the Bay Area Rapid Transit District, Greyhound Lines, and Franciscan Lines. Since 1974 the Metropolitan Transportation Commission has financed the collection, processing and analysis of the data. All this assistance is gratefully acknowledged. Helpful comments on the first draft of this report by Joel Markowitz and Leonard Newman are also greatly appreciated.

APPENDIX A

INDEPENDENT VARIABLES

POPL	3-County Population (Thousands)
MVREG	3-County Motor Vehicle Registration (Thousands)
TXSALES	3-County Taxable Sales (Millions of Dollars)
YEAR	Calendar Year (1/1/65 = Year Zero at the Bay Bridge) (1/1/67 = Year Zero at Caldecott)
PRINDX	SFSMA Consumer Price Index
ETOTL	5-County Total Employment (Thousands)
EMPL2	Mineral Extraction Employment (Thousands)
EMPL3	Contract Construction Employment (Thousands)
EMPL4	Manufacturing Employment (Thousands)
EMPL5	Transportation Employment (Thousands)
EMPL6	Trade Employment (Thousands)
EMPL7	Finance Employment (Thousands)
EMPL8	Services Employment (Thousands)
EMPL9	Government Employment (Thousands)
EBASIC	EMPL2 + EMPL3 + EMPL4 + EMPL5 (Thousands)
ESERV	EMPL6 + EMPL7 + EMPL8 + EMPL9 (Thousands)
E678	EMPL6 + EMPL7 + EMPL8 (Thousands)
GASCOST	Average price of 1 gallon of gasoline in 1967 cents

DEPENDENT VARIABLES

BBVV24	Bay Bridge vehicle volume, 24 hours, both directions
BBVVAM	Bay Bridge vehicle volume, 0600-0900, westbound
BBVVPM	Bay Bridge vehicle volume, 1600-1900, eastbound
BBVVMD	Bay Bridge vehicle volume, 0900-1600, both directions
BBMT24	Bay Bridge transit patronage, 24 hours, both directions
BBMTAM	Bay Bridge transit patronage, 0600-0900, westbound
BBMTPM	Bay Bridge transit patronage, 1600-1900, eastbound
BBMTMD	Bay Bridge transit patronage, 0900-1600, both directions
BBOCCP	Bay Bridge weighted passenger car occupancy factor, 0630-1830, both directions
CTVV24	Caldecott Tunnel vehicle volume, 24 hours, both directions
CTVVAM	Caldecott Tunnel vehicle volume, 0600-0900, westbound
CTVVPM	Caldecott Tunnel vehicle volume, 1600-1900, eastbound
FRRVV	Fish Ranch Road vehicle volume, 24 hours, both directions as a percentage of total Route 24 traffic west of Orinda.

APPENDIX B

DEMOGRAPHIC DATA USED IN THE MULTIPLE REGRESSION ANALYSIS

Year	Spring or Fall	3-County Population x 10^3	5-County Employment Total x 10^3	5-County Employment Basic x 10^3	5-County Employment 678* x 10^3	Taxable Sales Raw x 10^6	Taxable Sales Adjusted+ x 10^6	3-County Motor Vehicle Registration x 10^3	Gasoline Price Raw ¢	Gasoline Price Adjusted+ ¢
1965	Spring	2,241	NA	NA	NA	4,606	4,864	1,257	33.9	35.8
	Fall	2,250	NA	NA	NA				32.9	34.7
1966	Spring	2,259	1,121	384	501	4,823	4,967	1,277	32.9	33.9
	Fall	2,272	1,156	397	514				33.9	34.9
1967	Spring	2,290	1,144	375	513	4,885	4,885	1,475	34.9	34.9
	Fall	2,302	1,195	402	532				34.9	34.9
1968	Spring	2,309	1,192	385	541	5,275	5,047	1,350	34.9	33.4
	Fall	2,314	1,238	414	556				34.9	33.4
1969	Spring	2,317	1,243	403	567	5,572	5,056	1,633	35.9	32.6
	Fall	2,325	1,273	417	583				35.9	32.6
1970	Spring	2,337	1,260	401	583	5,594	4,831	1,654	36.9	31.9
	Fall	2,346	1,246	390	584				35.9	31.0
1971	Spring	2,352	1,230	377	578	5,916	4,926	1,723	29.9	24.9
	Fall	2,356	1,239	380	587				35.9	29.9
1972	Spring	2,356	1,240	368	596	6,485	5,217	1,792	32.9	26.5
	Fall	2,355	1,258	372	609				36.9	29.7
1973	Spring	2,353	1,289	376	631	7,289	5,543	1,810	36.9	28.1
	Fall	2,350	1,318	393	652				39.6	30.1
1974	Spring	2,346	1,307	379	648	8,104	5,612	1,955	52.1	36.1
	Fall	2,345	1,339	394	665				52.0	36.0
1975	Spring	2,346	1,317	365	660	8,563	5,382	1,978	53.1	33.4
	Fall	2,349	1,355	374	687				58.1	36.5
1976	Spring	2,354	1,345	363	690	9,552	5,537	1,891	55.6	33.3
	Fall	2,354	1,377	370	707				59.3	35.5

* Employment in the trade/finance/service industries.

\+ Adjusted to constant 1967 dollars using the consumer price index.

APPENDIX C

EFFECT ON CAPACITY OF DROP IN HEAVY VEHICLE TRAFFIC

	BAY BRIDGE Peak Half Hour		CALDECOTT TUNNEL Peak Half Hour	
	Westbound	Eastbound	Westbound	Eastbound
Increase in total traffic	271	131	454	294
Decrease in bus traffic	- 86	- 60	- 38	- 35
Change in truck# traffic	+ 10	- 83	- 2	- 18
Net change in heavy vehicle traffic	-76 (12%)	-143 (22%)	-40 (35%)	-53 (51%)
Probable increase in capacity due to new auxiliary lane	--	--	200	--
Hypothesized increase in flow due to fewer heavy vehicles	271	131	254	294
Implied PCU* equivalent per heavy vehicle	4.6	1.9	7.4	6.5

Heavy trucks and tractor-trailer combinations only.

* PCU = passenger car units.

Source: Total traffic data from data sets described in Section 3.2, used for the analysis of the shape of peak period curves. Bus and truck traffic from the same surveys, but representing only one count per period, or four days total for each "before" and "after" condition. Truck data show a large variance, and must therefore be viewed with suspicion.

APPENDIX D

A Note on the PBTB Predictions

In the Composite Report prepared by Parsons, Brinckerhoff-Tudor-Bechtel (PBTB) for the electorate in 1962, the consultants estimated the impact which BART would have on traffic crossing four major gateways in the Bay Area. Two of these are the Bay Bridge and Caldecott Tunnel. It is interesting to evaluate these predictions with the actual traffic count, always keeping in mind that PBTB assumed BART to be operating at 90-second headways and high levels of reliability by 1975. The comparison is shown below.

COMPARISON OF PBTB'S PREDICTIONS TO ACTUAL TRAFFIC

	PEAK HOUR PERSON TRIPS -- 1975 (average of morning and afternoon peaks)			
	TRANSBAY		CALDECOTT TUNNEL	
	Number on Transit	Percent of All Trips	Number on Transit	Percent of All Trips
PBTB*	16,700	55%	5,900	35%
Actual (ITS surveys)	16,570	56%	6,190	37%
PBTB high(+) or low(-)	+0.8%	-1%	-4.7%	-2%

Through a combination of experienced judgment and, doubtlessly, luck, PBTB made excellent predictions of total traffic and modal split at these two gateways. They were wrong, of course, in assuming that all transit passengers would be on BART, whereas a substantial proportion in fact are still traveling on buses through these gateways. However, considering the lack of travel demand theory available in 1962, this prediction deserves nothing but the highest admiration.

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*Parsons, Brinckerhoff-Tudor-Bechtel. Composite Report Bay Area Rapid Transit. San Francisco, May 1962. Page 85, Table VII.